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# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY,

CONTAINING

PAPERS, ABSTRACTS OF PAPERS, AND

REPORTS OF THE PROCEEDINGS

OF THE SOCIETY

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# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY.

Vol. XLVII. November 12, 1886. No. 1

J. W. L. Glaisher, M A., F.R.S., President, in the Chair.

Maurice Loewy, the Observatory, Paris; and
G. Spörer, Astrophysical Observatory, Potsdam,

were balloted for and duly elected Associates of the Society.

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*A Reply to Mr. Neison's Strictures on Delaunay's Method of Determining the Planetary Perturbations of the Moon.* By G. W. Hill.

For several years past Mr. Neison has been maintaining in the *Monthly Notices* and *Memoirs* of the Society that Delaunay's investigation of the two long period inequalities in the Moon's motion arising from the action of *Venus* is seriously defective, on account of the omission by him of a certain class of terms. In the *Monthly Notices* for last June there appears a long article by him upholding this view; to this I wish more especially to direct attention.

At the outset I may be allowed to say that all this criticism is without foundation. It appears to arise, partly from the very confused conception Mr. Neison seems to have of the nature of Delaunay's method, and partly because he fails to notice that Delaunay, after setting the degree of approximation he wishes to attain, always rigorously adheres to it. If we were obliged to admit the validity of *all* the statements in this article, an easy corollary from them would be that Lagrange's general method of the variation of arbitrary constants in the problems of mechanics was a blunder. Now, I think that no one acquainted with this method could, for a moment even, entertain such a

proposition. Hence we may conclude there is some flaw in the reasoning of this Paper. But this must be substantiated by noticing *seriatim* the objectionable points.

In the first place, why bring forward Hansen's published values of the coefficients of these inequalities for the purpose of throwing discredit upon Delaunay's values, when their author, himself, virtually confesses he has no confidence in them, by saying he had computed them in two different ways, and found essentially different results? And, to the very end of his life, he appears never to have been able to find out whether one of these results was right, and which it was, or whether both were wrong. It would be an amusing circumstance should it turn out that the set of values, withheld from publication by Hansen, were identical with those of Delaunay.

There is some inexactitude in Mr. Neison's statement, regarding the degree of approximation adopted by Delaunay in calculating the coefficient whose argument is $8l'' - 13l'$. In this connection we note that, on account of the close proximity of the Moon to the Earth, a planet cannot produce in her motion inequalities of the same order with those it produces in the Earth, but that they are only of the order of these multiplied by the solar disturbing force; and this is as true of the indirect action as of the direct. Now, on referring to Delaunay's work, we see that he has considered, not only the term of the lowest order in each portion of the coefficient, but also multiples of this by $m^2$. Hence, it is correct to say that he has considered terms of the order of the mass of *Venus* multiplied by the square of the solar disturbing force, but not those multiplied by the cube of the latter.

Mr. Neison regards the evidence adduced in his earliest Paper, as conclusively establishing the omission by Delaunay of a certain class of terms. But what was this evidence? Simply, that Hansen was at variance with Delaunay. Now, since Hansen was as much at variance with himself as he was with Delaunay, what weight ought to be attributed to this evidence? Then, Mr. Neison believes that certain discrepancies between results, obtained on the one hand by himself, and, on the other, by M. Gogou and myself, have their origin in the same cause. Now, if Hansen's investigation and also Mr. Neison's were accessible, this point could be immediately pronounced upon; but since they are not, it appears useless to speculate on the matter.

Mr. Neison says (p. 416), "He (Delaunay) substitutes the preceding value for the term in the disturbing function with the argument $\zeta$ in the differential equation and integrates." This does not correctly represent what Delaunay does. For he substitutes in the differential equation not only the term factored by $\cos \zeta$, but also the non-periodic portion of $R$: to wit, in the memoir of 1862, the terms

$$\frac{\mu}{2a} + m'\frac{a^2}{a'^3}\left[\frac{1}{4} + \frac{3}{8}c^2 + \frac{225}{64}e^2\frac{n'}{n} - \left(\frac{31}{32} - \frac{971}{32}e^2\right)\frac{n'^2}{n^2}\right],$$

and, in the memoir of 1863, the terms

$$\frac{\mu}{2a}+m'\frac{a^2}{a'^3}\left[\frac{1}{4}-\frac{3}{2}\gamma^2+\frac{3}{8}e^2+\frac{3}{8}e'^2\right].$$

The terms differ in the two cases, because the degree of approximation aimed at requires the preservation of different terms with allowable neglect of all the rest. From this non-periodic portion of R results, in both cases, much the larger part of the two inequalities considered. Mr. Neison's failure to note this completely invalidates his argument on the two following pages, by which he attempts to prove the incompleteness of Delaunay's procedure. And, in this connection, it may be noted that it is not necessary that the coefficient in (38) should vanish identically in order to prove Delaunay right; it is necessary only that it should turn out of such an order of smallness as to prove that the adopted degree of approximation had been attained.

On p. 417 it is said that the coefficients B and B′ "only differ by small quantities, unimportant for the present purpose." So far from this being the case, the difference B′ − B constitutes one portion of the terms which Mr. Neison, all along, has been asserting were neglected by Delaunay.

That Delaunay, in treating the two *Venus* inequalities, discarded his own method, and employed the old one recommended by Poisson, is erroneously stated on p. 423. The fact is that the method followed is the same as that he had used in deriving the solar perturbations. Next, Delaunay is found fault with (p. 424) because he confines himself to calculating in R the term which has the argument of the particular inequality he is dealing with; while it is plain that there are a multitude of terms in R, having other arguments, which could contribute to the value of the coefficient sought. This is true, but Delaunay's reasons for passing by these terms are quite evident. In the first place, it must be remembered that his final expression for the inequality is a formula of substitution, which must be made, not only in the mean longitude of the Moon, but also in the equation of the centre, in the evection, variation, and in all the inequalities arising from solar action. Hence, Delaunay's method of treatment enables him to obtain, with very little additional labour, all the terms in the expression for the *true* longitude which involve the very small divisor arising from the slow motion of the argument which he is considering; and that whatever may be their arguments. And, secondly, while the terms in R, having other arguments, which would be treated by Delaunay as giving rise each to a distinct transformation, can, in a strict sense, add something to the coefficient of the inequality in the *true* longitude, practically these terms are insensible; for, although they may be of the same order, before integration, as the quantities retained, they are altogether independent of the excessively small divisor which arises from the slow motion of

the argument of the inequality. As illustrating this point, it may be remarked that, in the case of the two *Venus* inequalities in question, we get such relatively large coefficients as 16″ and 0″·27 only by multiplying the corresponding terms in R by factors which are about 15,000,000 in the first, and 10,000,000 in the second inequality. Hence, if there are other terms, which rigorously ought to be added to the preceding values, but which, while in other respects of the same order of smallness, have factors not much exceeding unity, it is very apparent they may be neglected.

In the next place we find Delaunay charged with neglecting every term of the solar perturbations save the term of the lowest order in the variation in calculating the proper form for R. And it is said that his development "in no sense depends on his method of transformed elements, though made to appear as if it does; nor does it differ in any way from the values hitherto employed by astronomers save in being somewhat less complete." These statements misrepresent Delaunay. He arranges under four different heads the transformations made by him, and they involve no less than 16 out of the 57 operations of his first volume, besides 4 complementary ones. And whether the amount of work in this be regarded as much or little, I have ascertained that it is precisely sufficient to obtain the degree of approximation he proposes in the coefficients B, viz., to terms involving $m^2$. Carrying the approximation farther could only have afforded him terms of a higher order. It is, of course, open to Mr. Neison to say he deems this degree of approximation insufficient; and nothing can be said in opposition. But this is very different from saying Delaunay has committed errors. Again, I am not aware of the existence of any published investigation in which the degree of approximation is greater.

The reasoning Mr. Neison employs to show that Delaunay deserts, in this investigation, his own method and returns to the old method recommended by Poisson, is certainly very strange. He notes that the differential equation used has nothing in it to distinguish it from the corresponding one which Poisson would have used. But from what circumstance does this state of things arise? Simply because it is Delaunay's habit to omit, in the statement of his equations, every term which gives rise, in the final result, only to terms of a higher order than he has agreed to retain. The factors in question, in Delaunay's method, can be expressed only as infinite series; it is necessary, therefore, to cut them off at some point, and he determines this point in the way just stated. If reference is made to the same equation, in the memoir where Delaunay treats the other *Venus* inequality, it will be found to be duly distinguished by the presence of additional terms, Delaunay writing as many as are just sufficient for his purpose.

Mr. Neison next notices two assumptions, which he says have been made by Delaunay in his integration.

The first is that the factor $\frac{2}{an}$, which multiplies $\frac{dR}{dl}$, is treated as if it were constant. But here he forgets that, with Delaunay, at this stage of the work, the symbols $a$, $e$, $\gamma$, $l$, $g$, and $h$, denote quantities which have no solar perturbations; and that, consequently, the deviation of $\frac{2}{an}$ from a constant has the mass of the planet as a factor. Thus, as $\frac{dR}{dl}$ already has this factor, the additional terms, which would in this manner arise, would have the square of the mass of the planet as factor; these, as all other investigators, Delaunay expressly neglects.

With regard to the second assumption, in reference to which Mr. Neison makes what he thinks his chief point against Delaunay, let us consider what is the essential difference between Delaunay's method and that employed by the earlier investigators. Delaunay said to himself, Do not let us go back to the elements of the Keplerian ellipse every time we have to consider the action of a new force on the Moon, but let us determine our new wave of motion in such a way that it may be superposed on the curve which the Moon would describe under the action of all the forces previously considered, instead of on the Keplerian ellipse. At any stage of progress, in expressing the Moon's co-ordinates, there must, of necessity, appear in them six arbitrary constants which have been introduced by integration. Let us take these as variables, instead of the six elements of the Keplerian ellipse. This course demands that the differential equations employed by the earlier investigators should be somewhat modified. The modification appears as a change in the values of the quantities which Poisson denoted generally by the symbol $[a, b]$. Now, just as it would be absurd to maintain that the elements of the Keplerian ellipse suffer perturbations from the action of a centrobaric Earth, so it is absurd to maintain that the quantities $a, e, \gamma, l, g$ and $h$, employed by Delaunay after he has got through with the solar perturbations and has arrived at the treatment of the planetary perturbations, and which are the elements of the curve which would be described by the Moon under the combined action of the Earth and Sun, suffer perturbations from the latter body. Yet Mr. Neison's argument, when divested of its obscurities, is seen to be nothing more or less than a plea that these quantities do suffer perturbations from the Sun.

To make the matter plainer, let us suppose that Delaunay, groping about in the dark, had fallen upon the Poissonian equations, and, thinking them to be his own, had used them as such; and, moreover, on making his substitutions, had made them only in the elliptic portion of the co-ordinates. Then he would have committed the very error Mr. Neison lays to his charge. But since he uses equations suitably modified to the new signification of the quantities $a$, $e$, &c., and, moreover, makes his substitutions in the complete expressions for the

Moon's co-ordinates, and not in the elliptic portion only, as the earlier investigators do, is it not plain that, by these two modifications, he obtains terms which he would not have obtained in the former supposed case? Now these terms, in sum, are precisely equivalent to those Mr. Neison accuses him of neglecting by omitting to include R''' in his disturbing function. Thus it is seen that Delaunay takes account of R''' in an indirect manner, the peculiar nature of his method absolving him from considering the terms arising from R''' as a separate class.

Perhaps the matter will be clearer still if we say that, just as in determining the solar perturbations we have no class of terms of the order of the product of the mass of the Earth by the mass of the Sun, simply because the Earth's action is considered as the principal force, so when we come to treat the planetary perturbations by Delaunay's method, there is no special class of terms of the order of the product of the Sun's mass by the planet's mass, for the reason that here the combined actions of the Earth and Sun are regarded as forming the principal force.

Next we must not pass over without notice the quite erroneous method Mr. Neison proposes (pp. 430, 431) for getting the proper expressions for the Poissonian quantities $[a, b]$; viz., by substituting for the elements in the expressions proper to the older form of the differential equations their complete values as functions of the time, and then neglecting all the periodic terms. It is very certain this procedure will not give the same values as Delaunay has, who obtains them by taking the partial derivatives of $a$, $e$, and $\gamma$ with respect to the elements $L$, $G$, and $H$, which are the conjugates of $l$, $g$, and $h$.

Mr. Neison is not content with what he has already said to establish the serious imperfection of Delaunay's method, but fortifies himself in the belief of it by a new line of argument (pp. 432–437), where he gives his conception of the essential nature of Delaunay's transformations. But his argument is fatally vitiated because he will have it that the transformations in question are rigorously linear in their operation. Thus, to illustrate, suppose Delaunay has

*Operation* 1.

Replace $a_0$ by $a_1 + f_1(a_1, e, \text{\&c.})$

*Operation* 2.

Replace $a_1$ by $a_2 + f_2(a_2, e_2, \text{\&c.})$

(I use the subscripts, which Delaunay has not, that my meaning may be clear.) According to Mr. Neison's way of looking at things, these two operations are equivalent to

Replace $a_0$ by $a_2 + f_1(a_2, e_2, \text{\&c.}) + f_2(a_2, e_2, \text{\&c.})$

Thus he fails to see that Delaunay intends the $a_1$, under the functional sign $f_1$, to be eliminated by the substitution of Operation 2, as well as the $a_1$ which is outside of it. In consequence he misses all the terms which are of the order of the product of $f_1$ by $f_2$.

Now, suppose that $f_1$ belongs to an operation which is concerned with solar perturbations, and $f_2$ to one concerned with planetary perturbations. Then Mr. Neison, by his erroneous interpretation of Delaunay's processes, fails to get some terms of the order of the product of the masses of the Sun and planet, which, nevertheless, Delaunay has. Now, these are the very terms Delaunay is accused of neglecting. And, what is sufficiently singular, Mr. Neison appears to regard the symbols $a$, $e$, &c., which are under the functional signs $f_1$, $f_2$, &c., as having everywhere throughout the whole series of operations the same signification, and as being absolute constants; so that, for him, all the $f$'s are explicit functions of the time.

There is another way in which Mr. Neison's error may be illustrated. Suppose we write one of the differential equations of the Moon's motion in rectangular co-ordinates, thus

$$\frac{d^2x}{dt^2}-\frac{d\Omega_0}{dx}=\frac{dR^{(0)}}{dx}+e'\frac{dR^{(1)}}{dx}+e'^2\frac{dR^{(2)}}{dx}+\ .\ .\ .\ +\beta\frac{dR_0}{dx}+m''\frac{dR_1}{dx}+\&c.,$$

where $\Omega_0$ denotes the potential of the force exerted by a centrobaric Earth; and the portion of the disturbing function due to solar action has been broken into a number of parts $R^{(0)}$, $e'R^{(1)}$, $e'^2R^{(2)}$, &c., severally proportional to the various powers of the solar eccentricity $e'$; and $\beta R_0$ is the portion due to the figure of the Earth, $\beta$ being a constant which measures the deviation of the Earth from a centrobaric body; in fine, $m''R_1$, is the portion due to the action of a planet whose mass is $m''$. Then Delaunay's way of proceeding is very similar to this: he first ascertains what would be the expressions for the Moon's coordinates were $R^{(0)}$ the complete disturbing function, by making variable the $a$, $e$, $\gamma$, $l$, $g$, and $h$ which appear in the elliptic formulæ; he then transposes $R^{(0)}$ over to the left member of the equation, and the potential of the principal force is now no longer $\Omega_0$ but $\Omega_0 + R^{(0)}$; he then proceeds to treat $e'R^{(1)}$ as if it alone constituted the whole of the disturbing function, using the elements $a$, $e$, $\gamma$, $l$, $g$, and $h$, which stand in his last expressions for the co-ordinates as variables, not those which belong to the elliptic expressions. When this is done, $e'R^{(1)}$ is transferred to the left member, and the potential of the principal force is now $\Omega_0 + R^{(0)} + e'R^{(1)}$, and the work is continued as before.

Now, Mr. Neison admits the legitimacy of all this as long as we are dealing with the portions of the disturbing function which arise from solar action; but says that, the moment we arrive at the term $m''R_1$, all changes. Then certain ghosts, as it were, of the portions $R^{(0)}$, $e'R^{(1)}$, &c., unbidden return to the

right member and trouble the portion $m''R_1$. Thus we have the strange spectacle of forces figuring at once as principal and as disturbing. Mr. Stockwell made a precisely similar objection to my elaboration of the inequalities due to the figure of the Earth, which was disposed of by Prof. Adams in a single sentence.

If all this be true, what becomes of the assertion, often reiterated, that, when the differential equations are written down, all the rest is a pure question of analysis? On Mr. Neison's and Mr. Stockwell's view, the analyst, who does the integrating, needs an astronomical or mechanical prompter at his elbow to inform him of the exact physical import of the constants $\beta$ or $m''$, otherwise he will infallibly go wrong.

*Washington,*
1886, *Oct.* 14.

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## *On Kepler's Problem.* By Robert Bryant, B.A., B.Sc.

The solutions of this problem are usually given with a view of obtaining the eccentric anomaly directly from a series expanded in powers of the eccentricity, the application of which is in general very laborious.

The use of the differential formula

$$\frac{dE}{dM}=\frac{1}{1-e\cos E},$$

when an approximate value of E in a planetary orbit is known, involves less labour, while the results converge with great rapidity.

The two following series are given as readily offering the required approximate value of E in a planetary orbit, when one application of the differential formula usually gives the eccentric anomaly with sufficient accuracy. The series are so simple and so readily present themselves that they have probably been given before, but I have not met with them.

We have $M=E-e\sin E$ with M and $e$, given to find E.

Lagrange's theorem may be concisely expressed thus:

If

$$y=z+x\phi(y),\text{ then } f(y)=\sum_{n=0}^{n=\infty}\frac{x^n}{\lfloor n}\,\frac{d^{n-1}}{dz^{n-1}}\left\{\phi(z)^n f'(z)\right\},$$

the interpretation of which when $n=0$ is obvious.

If we expand sin E and cos E, we obtain

$$\sin E=\sin M+e\sin M\cos M+\frac{e^2}{2}\sin M(2-3\sin^2 M)+\frac{e^3}{3}\sin M\cos M(3-8\sin^2 M)$$

$$+\frac{e^4}{24}\sin M(24-136\sin M+125\sin^4 M)+\ldots.$$

$$\cos E=\cos M-e\sin^2 M-\frac{3e^2}{2}\sin^2 M\cos M-\frac{2e^3}{3}\sin^2 M(3-4\sin^2 M)$$

$$+\frac{5e^4}{24}\sin^2 M\cos M(12-4\sin^2 M)+\ldots.$$

These series are generally unsuited for the evaluation of E; but if we multiply them by sin M and cos M respectively, we get on addition

$$\cos(\mathrm{E}-\mathrm{M}) = 1 - \frac{e^2}{2}\sin^2\mathrm{M} - e^3\sin^2\mathrm{M}\cos\mathrm{M} - \frac{e^4}{24}\sin^2\mathrm{M}\,(36-49\sin^2\mathrm{M}) \ldots.$$

or

$$\sin^2\tfrac{1}{2}(\mathrm{E}-\mathrm{M}) = \frac{e^2\sin^2\mathrm{M}}{4}(1+2e\cos\mathrm{M}) + \frac{e^4}{24}\sin^2\mathrm{M}\,(36-49\sin^2\mathrm{M}) \quad \text{(A)}$$

$$= \frac{e^2\sin^2\mathrm{M}}{4}(1+2e\cos\mathrm{M}) + \frac{e^4}{2}\sin\mathrm{M}\sin 3\mathrm{M} \text{ nearly} \quad \text{(B)}$$

If, as Mr. Glaisher has suggested to me, we extract the square root of each side of (A), we get

$$\sin\tfrac{1}{2}(\mathrm{E}-\mathrm{M}) = \tfrac{1}{2}e\sin\mathrm{M}\left\{1+e\cos\mathrm{M}+\frac{e^2}{12}(30-43\sin^2\mathrm{M})\right\}\text{ nearly}$$

$$= \tfrac{1}{2}e\sin\mathrm{M}\left\{1+e\cos\mathrm{M}+\frac{5e^2}{6}\frac{\sin 3\mathrm{M}}{\sin\mathrm{M}}\right\}\text{ nearly} \quad \text{(C)}$$

In (B) and (C) the term involving sin 3 M may be neglected in obtaining an approximate value of E.

Again, in the above expression for Lagrange's theorem, if for a particular value of $n$ we can make the quantity within the brackets constant, the corresponding term in $f(y)$ will vanish.

As the form of the function $f$ is completely at our disposal, we may for a particular value of $n$ put

$$\phi(z)^n f'(z) = \text{const.}$$

or

$$f(z) = a\int\frac{dz}{\phi(z)^n}$$

In the present case $\phi(\mathrm{M}) = \sin\mathrm{M}$.

If $n=1$, we derive but little assistance.

If $n=2$, we get $f(\mathrm{M}) = \cot\mathrm{M}$ (omitting a constant multiplier), and $e^2$ will not appear in our result.

If $n=3$,

$$f(\mathrm{M}) = -\frac{\cos\mathrm{M}}{2\sin^2\mathrm{M}} + \tfrac{1}{2}\log\tan\frac{\mathrm{M}}{2},$$

which is too complicated to assist us.

For values of $n$ greater than $3$ $f(\mathrm{M})$ is equally unsuitable.

Expanding, then, cot E, we get

$$\cot\mathrm{E} = \cot\mathrm{M} - \frac{e}{\sin\mathrm{M}} + \frac{e^3}{6}\sin\mathrm{M} + \frac{e^4}{3}\sin^2\mathrm{M}$$

$$-\frac{e^5}{40}\sin\mathrm{M}\,(27\sin^2\mathrm{M}-20)\ldots.$$

$$= \frac{\cos\mathrm{M}-e}{\sin\mathrm{M}} + \frac{e^3}{6}\sin\mathrm{M}\text{ nearly} \quad \text{(D)}$$

The introduction of the term in $e^3$ is easily effected, and when M falls near $\pm 90°$, it is better to consider it, in which case it is evident that the terms involving $e^4$ and $e^5$ are very small.

In the first formula the sign of E − M is the same as that of sin M.

In the second formula, E > or < 180°, according as M > or < 180°. This fact and the sign of cot E are sufficient to determine the quadrant in which E is to be taken.

The following example will sufficiently illustrate the deduction of E by the methods above mentioned:

Suppose M = [illegible] for the planet *[illegible]* ([illegible]), for which e = [illegible].

| Formula C | | Formula D | |
|---|---|---|---|
| e | [illegible] | e | [illegible] |
| sin M | −[illegible] | [illegible] | [illegible]* |
| e | [illegible] | cos M | −[illegible] |
| cos M | −[illegible] | | [illegible] |
| e cos M | −[illegible] | cos M − e | −[illegible] |
| | [illegible] | sin M | −[illegible] |
| $\frac{1}{1 - e \cos M}$ | [illegible]* | cot E | [illegible] |
| ½ e sin M | −[illegible] | E | [illegible] |
| sin ½(E − M) | −[illegible] | | |
| ½(E − M) | −[illegible] | | |
| E − M | −[illegible] | | |
| E | [illegible] | | |

Having obtained an approximate value of E, we shall be greatly assisted in obtaining its true value by considerations such as the following.

In the first series the principal term neglected depends on sin M $\frac{\sin 3M}{\sin M}$, or sin 3M, which in this case is positive. Hence the deduced value of E is too small.

In the second series the principal term neglected depends on sin M, which in this case is negative. Hence the deduced value of cot E is too great, and since E lies in the third quadrant, it follows that E is too small.

If we then increase E by a few minutes of arc, we can work the results side by side with but little extra labour, the requisite logarithms being taken out at the same time.

The correct value of E being unknown, the values adopted were [illegible] and [illegible]. With these the calculation is as follows:—

* From [illegible]

| | | |
|---|---|---|
| $e$ | 9·29078 | 9·29078 |
| sin E | −9·93855 | −9·93898 |
| Radius in minutes | 3·53627 | 3·53627 |
| $e'$ sin E | −2·76560 | −2·76603 |
| Natural number | −582′·91 = −9° 42′·91 | −583′·49 = −9° 43′·49 |
| E | 240° 14′ | 240° 20′ |
| Deduced value of M | 249 56·91 | 250 3·49 |
| $d$ M | + 3·09 | − 3·49 |

We have thus, it will be seen, overstepped the true value of E in our estimate.

We have also

| | | |
|---|---|---|
| 1 − $e$ cos E | 0·04430 | 0·04416 |
| $d$ M | + 0·48996 | − 0·54283 |
| $d$ E | + 2′·790 | − 3′·153 |
| E | 240° 16′·790 | 240° 16′·847 |

The mean of these differs from the true value of E by only 0″·31. Using seven figure logs we find E = 240° 16′ 49″·41.

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*Note on the Star γ Equulei.* By George Knott, B.A., LL.B.

In the spring of last year Mr. Hind pointed out to me that, in view of the Proper Motion of the star γ *Equulei*, there was ground for the inference that a small 11 mag. companion, detected by me in July 1867, was in physical connection with it. I have been hoping accordingly to obtain further measures of the pair, but have failed doing so until the present month.

I give below the results of the measures hitherto obtained by myself, together with a set by Mr. Burnham at an intermediate epoch:

| | | | |
|---|---|---|---|
| 1867·52 | P = 276°·83 | D = 2″·173 | Knott. |
| 1867·57 | 276·85 | 2·089 | —— |
| 1871·61 | 277·62 | 1·875 | —— |
| 1877·72 | 274·5 | 2·1 | Burnham. |
| 1886·83 | 273·76 | 2·058 | Knott. |
| 1886·84 | 272·70 | | —— |

The measures of 1871·61 were taken under unfavourable circumstances, as appears from the note:—"B only to be seen on the most careful scrutiny; obs. most difficult." At my last epoch clouds came over before any measures of distance could be obtained. Mr. Burnham adds another small star, 12 mag., which I have not yet seen. His co-ordinates for it are: P = 10°·0, D = 41″·3, Ep. 1877·72. It seems desirable that this star should be re-measured.

If now we take* the Proper Motion values assigned by Prof. Auwers, viz.:—in R.A. $+0^{s}\cdot0022$ and in Decl. $-0''\cdot167$, and starting from the epoch 1867·54 compute the present values of P. and D. on the assumption that the companion does not share in the motion of the principal star, we get $P=321^{\circ}\cdot72$, $D=4''\cdot428$. A comparison of these numbers with my latest measures points distinctly to the conclusion that a physical connection subsists between the objects. The series of measures as a whole appears further to indicate a slight but decided decrease in the angle of position of the companion in nineteen years, while no change would seem to have taken place in the distance.

*Knowles Lodge, Cuckfield:* 1886, *November* 10.

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## *On the Orbit of* Σ 1757. By J. E. Gore.

I have computed the orbit of this binary star, by means of the graphical method, and find the following provisional elements:

*Elements of* Σ 1757.

| | |
|---|---|
| $P = 340\cdot38$ years. | $\Omega = 89^{\circ}\,45'$. |
| $T = 1778\cdot81$. | $\lambda = 203^{\circ}\,14'$. |
| $e = 0\cdot2425$. | $a = 2''\cdot25$. |
| $\gamma = 45^{\circ}\,51'$. | $\mu = +1^{\circ}\cdot057$. |

The following is a comparison between the recorded observations, and the positions computed from the above elements:

| Epoch. | Observer. | $\theta_o$ | $\theta_c$ | $\theta_o-\theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o-\rho_c$ |
|---|---|---|---|---|---|---|---|
| | | ° | ° | ° | ″ | ″ | ″ |
| 1825·37 | Struve | 10·0 | 10·75 | −0·75 | 1·60 | 1·38 | +0·2 |
| 1829·82 | „ | 19·5 | 18·55 | +0·95 | 1·44 | 1·45 | −0·0 |
| 1832·39 | Smyth | 24·1 | 23·0 | +1·10 | 1·5 | 1·49 | +0·01 |
| 1833·38 | Struve | 23·9 | 24·6 | −0·70 | 1·54 | 1·50 | +0·04 |
| 1835·37 | „ | 25·5 | 27·6 | −2·10 | 1·66 | 1·53 | +0·13 |
| 1836·42 | „ | 29·4 | 29·1 | +0·30 | 1·64 | 1·54 | +0·10 |
| 1838·48 | Smyth | 31·0 | 32·1 | −1·10 | 1·7 | 1·60 | +0·10 |
| 1841·38 | Mädler | 36·0 | 36·1 | −0·10 | 1·74 | 1·63 | +0·11 |
| 1842·39 | Dawes | 37·4 | 37·4 | 0·00 | 1·67 | 1·66 | +0·01 |
| 1842·52 | Smyth | 37·9 | 37·5 | +0·40 | 1·7 | 1·66 | +0·04 |
| 1843·45 | Dawes | 38·8 | 38·75 | +0·05 | — | 1·69 | — |
| 1843·51 | Kaiser | 40·9 | 38·8 | +2·10 | — | 1·69 | – |
| 1844·72 | O. Struve | 43·7 | 40·2 | +3·50 | 1·89 | 1·71 | +0·18 |
| 1845·88 | Mädler | 40·8 | 41·7 | −0·90 | 2·02 | 1·74 | +0·28 |

* I am indebted for these numbers to Mr. Hind.

| Epoch. | Observer. | $\theta_o$ | $\theta_c$ | $\theta_o-\theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o-\rho_c$ |
|---|---|---|---|---|---|---|---|
| 1850·38 | O. Struve | 48°·8 | 46°·8 | +2°·00 | 1″·85 | 1″·82 | +0″·03 |
| 1852·38 | Smyth | 51·7 | 48·9 | +2·80 | 2·0 | 1·88 | +0·12 |
| 1853·09 | Mädler | 52·2 | 49·6 | +2·60 | 2·05 | 1·89 | +0·16 |
| 1853·73 | Jacob | 48·0 | 50·25 | −2·25 | 2·14 | 1·89 | +0·25 |
| 1854·37 | Mädler | 50·1 | 50·85 | −0·75 | 2·16 | 1·90 | +0·26 |
| 1855·31 | „ | 51·3 | 51·8 | −0·5 | 1·7 | 1·93 | −0·23 |
| 1856·32 | „ | 51·8 | 52·75 | −0·95 | 1·5 | 1·95 | −0·45 |
| 1856·42 | Morton | 51·9 | 52·85 | −0·95 | 2·01 | 1·95 | +0·06 |
| 1856·88 | Secchi | 52·9 | 53·35 | −0·45 | 1·84 | 1·95 | −0·11 |
| 1857·29 | Morton | 54·2 | 53·7 | +0·5 | 2·00 | 1·97 | +0·03 |
| 1858·08 | Jacob | 52·8 | 54·45 | −1·65 | 1·76 | 1·98 | −0·22 |
| 1858·37 | Mädler | 54·7 | 54·6 | +0·1 | 1·91 | 1·98 | −0·07 |
| 1859·36 | „ | 53·7 | 55·5 | −1·8 | 1·82 | 2·02 | −0·20 |
| 1860·34 | Dawes | 54·3 | 56·4 | −2·1 | 2·31 | 2·03 | +0·28 |
| 1860·35 | „ | 53·4 | 56·4 | −3·00 | 2·08 | 2·03 | +0·05 |
| 1863·32 | Dembowski | 59·0 | 58·96 | +0·04 | 2·01 | 2·09 | −0·08 |
| 1865·97 | „ | 60·4 | 61·0 | −0·6 | 2·09 | 2·13 | −0·04 |
| 1866·01 | O. Struve | 60·8 | 61·03 | −0·23 | 2·34 | 2·14 | +0·20 |
| 1867·27 | Talmage | 63·7 | 62·1 | +1·6 | 2·60 | 2·16 | +0·44 |
| 1868·30 | Dembowski | 62·7 | 62·8 | −0·1 | 2·04 | 2·18 | −0·14 |
| 1869·22 | Brünnow | 63·4 | 63·53 | −0·13 | 2·59 | 2·20 | +0·39 |
| 1869·24 | Talmage | 64·3 | 63·53 | +0·77 | — | 2·20 | — |
| 1870·15 | Dembowski | 63·5 | 64·2 | −0·7 | 2·03 | 2·22 | −0·19 |
| 1870·37 | Talmage | 64·1 | 64·3 | −0·2 | 2·00 | 2·22 | −0·22 |
| 1871·19 | Dembowski | 63·4 | 64·9 | −1·5 | 2·13 | 2·24 | −0·11 |
| 1872·33 | Wilson & Seabroke | 64·8 | 65·7 | −0·9 | 2·30 | 2·25 | +0·05 |
| 1872·37 | Talmage | 67·3 | 65·73 | +1·57 | — | 2·25 | — |
| 1873·23 | Wilson & Seabroke | 64·0 | 66·45 | −2·45 | 2·05 | 2·27 | −0·22 |
| 1873·35 | „ „ | 65·0 | 66·53 | −1·53 | 2·00 | 2·27 | −0·27 |
| 1874·32 | „ „ | 65·5 | 67·25 | −1·75 | 2·15 | 2·28 | −0·13 |
| 1874·32 | Talmage | 69·8 | 67·25 | +2·55 | (1·08)? | 2·28 | (−1·20)? |
| 1874·41 | Wilson & Seabroke | 64·2 | 67·31 | −3·11 | 2·16 | 2·28 | −0·12 |
| 1875·31 | Schiaparelli | 66·6 | 67·8 | −1·2 | 2·00 | 2·29 | −0·29 |
| 1876·36 | Wilson & Seabroke | 67·2 | 68·45 | −1·25 | 2·15 | 2·30 | −0·15 |
| 1876·41 | „ „ | 66·5 | 68·48 | −1·98 | 2·21 | 2·30 | −0·09 |
| 1879·40 | Hall | 68·9 | 70·5 | −1·60 | 2·33 | 2·35 | −0·02 |
| 1879·470 | Schiaparelli | 67·98 | 70·5 | −2·52 | 2·462 | 2·35 | +0·112 |
| 1882·467 | „ | 69·38 | 72·43 | −3·05 | 2·314 | 2·42 | −0·106 |
| 1883·21 | Engelmann | 70·44 | 72·8 | −2·36 | 2·623 | 2·43 | +0·193 |

The formulæ for calculation of an ephemeris are as follows:

$$(1)\quad u - 13^{\cdot}89 \sin u = +1^{\circ}{\cdot}057\,(t - 1778{\cdot}81),$$

$$(2)\quad \tan \tfrac{1}{2}V = 1{\cdot}28 \tan \tfrac{1}{2}u,$$

$$(3)\quad \tan(\theta_c - 89^{\circ}\ 45') = 0{\cdot}6965 \tan(V + 203^{\circ}\ 14').$$

$$(4)\quad \rho = 2''{\cdot}25\,(1 - 0{\cdot}2425 \cos u)\,\frac{\cos(V + 203^{\circ}\ 14')}{\cos(\theta_c - 89^{\circ}\ 45')};$$

where $u$ is the eccentric anomaly, and V the true anomaly for the epoch $t$, $\theta_c$ the required position angle, and $\rho$ the distance.

The position of the star is for 1886·0

R.A. $13^{h}\ 28^{m}\ 29^{s}$
$+0^{\circ}\ 16'\ 6''$.

It is Lalande 25087, and lies closely *np* $\zeta$ *Virginis.* It was estimated $7^{m}$ by Lalande, and 7·0 at Cordoba. According to Struve the magnitudes of the components are 7·8 and 8·9.

The orbit has been previously computed by Casey, who finds a period of 401·0 years, with T = 1797·42, and $e = 0{\cdot}5079$.

*Ballysodare, Co. Sligo:*
1886, *Oct.* 14.

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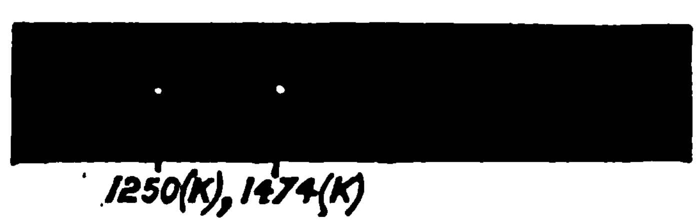
*Reply to certain Questions raised before the Royal Astronomical Society at the Meeting on* 1886, *March* 12, *concerning the matter detailed in a Paper entitled "Bright Lines in Stellar Spectra."* By O. T. Sherman.

(*Communicated by the Secretaries.*)

The object of the method employed is to render the image of the bright line light as broad and intense as may be, and the intensity of the background light a minimum. A successful application is presented in the spectrum of *Nova Andromedæ*, which is shown in an adjoining cut.* Along a faint bluish line




Portion of the Spectrum of Nova Andromedæ.

there were seen bright stellar images surrounded by a haze. These were termed bright lines.

In practice the background light is often sufficiently intense

* The haze surrounding the stellar image is somewhat exaggerated in the drawing.

to cut down the haze surrounding the point, so that the image appears as a bright knot, fuzzy or sharply bounded, beading or embedded in the bright linear spectrum. Such is the case with *β Lyræ* or *γ Cassiopeiæ*, as seen with the means at command.

One has to distinguish between bright line, bright background space, and mere disturbance in the light of the spectrum. The principle upon which the discrimination is made is that the bright background space being the effect of contrast remains constant in both place and intensity. The disturbance in the light of the star is constant in neither intensity nor position. The bright line is constant in place but not in intensity. For each star, therefore, an extended series of observations is necessary.

The first remarks made concern (*a*) the adjustment of the instrument; (*b*) the action of the lines; (*c*) the position of the cylindrical lens.

(*a*) "First, 'previous to each night's work, the instrument was adjusted upon the Sun; a solar spot when possible being brought sharply in focus on the jaws of the slit.' This would seem a proper and necessary adjustment, and would suffice for the centre of the spectrum; but for the extreme rays, especially the blue and violet, the spectroscope would not be in the proper focus of the equatorial. There is a paragraph in Mr. Sherman's Paper which at least suggests that the extreme ends of the spectrum suffered in this way. . . ." The adjustments of the spectroscope were such as to give good definition for the solar spectrum. It was presumed they would also for the stellar. The adjustments have been regarded. Also two-thirds of the lines announced for *γ Cassiopeiæ* lie between $D_3$ and H $\gamma^{(1)}$,* a space not encroaching very far on the extreme ends of the spectrum. It is thought the remark will hold generally true.

(*b*) "There is a paragraph in Mr. Sherman's Paper which at least suggests that the extreme ends of the spectrum suffered in this way: 'At the red end, under a sharp focus, they' (the bright lines) 'stand out the full breadth of the spectrum, bearing somewhat the same relation to the background as the prominences to the solar spectrum. In the brighter portion of the spectrum they are cut down to bright star points. At the blue end they become more distinct, but not so sharp as at the red. At times they shine with almost a metallic brilliancy; at other times they are faint, faded, and easily passed over. Certain sets appear to be prominent at times; others at other times.' It seems very difficult to believe that this can be a description of true stellar bright lines, while it is quite conceivable that lines due to some instrumental effect might present just such an appearance in a spectroscope, adjusted as Mr. Sherman's seems to have been, only for the centre of the spectrum. . . ."

There are at least two other observers who agree as to the

* American Journal of Science, Dec. 1885.

action of the bright line. A note taken from the *Astronomische Nachrichten*, Nos. 2651–2652, is copied from the *Observatory* of April, 1885.

"*Variations in the Spectrum of β Lyræ.*—In the summer and autumn of 1883, Dr. N. de Konkoly and Herr E. von Gothard detected a certain amount of variability in the C, $D_3$ and F lines in the spectra of γ *Cassiopeiæ* and β *Lyræ*, in which they are frequently seen to shine as bright lines. During 1884, Herr von Gothard has followed up his investigations and observed the spectrum of β *Lyræ* on thirty nights. On nine of these occasions the $D_3$ line was seen to be more or less bright. On July 13 it was even described as 'almost dazzling'; on several other nights its presence was only suspected; on ten nights no trace of it was seen, so that it presented on different occasions every possible degree of change of brightness from great brilliancy down to total disappearance. The C line was also seen to be reversed on many occasions, and was frequently very brilliant, but on others it was only faint, was difficult to see, or was evidently a dark line. The F line was not so often noticed to appear bright; its reversal would naturally be less easily observed than that of C or $D_3$. Herr von Gothard was not able to satisfactorily determine the length of the period of variability; it was evidently very short, and a period of about seven days seemed to suit the observations fairly well. It should be added that the three lines appear to vary in perfect accord with each other . . . ."

Again, "both show bright lines of hydrogen and helium, so that the peculiarity of their condition probably consists in the unusual extent and intense ignition of their chromospheric surroundings. But this condition is subject to fluctuations. The brilliant rays indicative of it died out during nine years, 1874–1883. . . ." *

Again, the bright lines of the solar chromosphere show a similar variation in both visibility and frequency, as is shown in the frequency and maximum brilliancy numbers in Young's "Catalogue of Bright Lines in the Spectrum of the Solar Atmosphere." †

Again, one might appeal to our knowledge derived from "new" or "temporary" stars—for example, the changes in the spectrum of T *Coronæ*.‡

Again, a similar action is not entirely unknown even in laboratory work. For the sake of an example we quote,§ "When the carbonic acid is displaced by hydrogen, the hydrogen lines appear, the hydro-carbon flame and the triple sets remaining bright, but in this gas the flame group at 4310 is particularly well marked, and *the carbon line at* 4266 *keeps flashing in occa-*

* History of Astronomy during the Nineteenth Century, Clerke, p. 420.

† American Journal of Science, Nov. 1872.

‡ History of Astronomy during the Nineteenth Century, Clerke, p. 422.

§ On the Origin of the Hydro-Carbon Flame Spectrum, Profs. G. D. Liveing and J. Dewar, Proc. Roy. Soc. Vol. 34, 1882–1883, p. 429.

*sionally.*" Or, in general, examples might be drawn from the whole range of phenomena showing change in spectra depending upon temperature or upon mechanical mixture with some other gas.*

(*c*) "Particularly as he placed his cylindrical lens not before the slit, nor even in the viewing telescope, but between the eye-piece and his eye."

The cylindrical lens need have and properly has no place in the arrangement. Used at the commencement of the work, it has long since been abandoned. As bearing on the point, however, the following quotation which has come to my knowledge within a day or two is not without interest. It comes from one who, having searched in the same field without being satisfied, makes suggestions for those that follow, "and to ask others with greater optical power to search for the lines, *taking the precaution to use the cylindrical lens close to the eye*, and not to apply it to the instrument until the rays to be examined are absolutely in focus on the slit, *if a slit is used*. It is possible scintillation may help matters." †

Under the second head is treated (*a*) the width of the slit; (*b*) the accuracy of the measures; (*c*) the generality of the appearances; (*d*) the fact that they have not been observed before.

Second (*a*). "Mr. Sherman used an unusually wide slit, '$5^{mm.}$ or more.' I think most stellar spectroscopists will pronounce this to have been fully 100 times too wide. $5^{mm.}$ in the focus of the 8-inch object-glass would correspond to 6′ of arc. It seems hard to see what purpose a slit of so great a width would serve, and in what essential feature it differed from no slit at all."

It practically is no slit at all. A glance at the quotation just above is not without interest. However wide the metallic jaws may be, the practical slit is the stellar diffraction shield for an eight-inch glass, about three seconds of arc in diameter. ‡

(*b*) "And it is also difficult to place much confidence in measures made with so wide a slit, especially as the collimator only measures 6 inches in focal length, so that no stress can be laid upon the correspondence between the bright lines observed and those seen in the solar chromosphere."

Since the practical slit is three seconds in place of six minutes, it is hoped that this objection falls. The light of the shield fades off rapidly towards the edge, leaving a sharp central point to be set upon, or a fuzzy disc to be bisected. The measures seem therefore, in point of accuracy, comparable with

* See the work of Profs. Liveing and Dewar, Proc. Roy. Soc. Vols. 27 and 36.

† Note on Bright Lines in the Spectra of Stars and Nebulæ. By J. Norman Lockyer. Proc. Roy. Soc. Vol. 27, p. 51.

‡ Hermann Struve, Mém. de l'Acad. Impériale des Sciences de St. Pétersbourg, VII<sup></sup>e Série, Tome XXX. No. 8. Airy, Transactions of the Cambridge Philosophical Society, Vol. V. part iii.

those obtainable with a slit somewhat less in width than the stellar diffraction image, and some stress seems due to their approximate agreement with the solar atmospheric lines. A greater conditioning circumstance seems to be the use of a thick wire.

(*c*) "The most suspicious circumstance of all, however, is, I think, that so far Mr. Sherman has never failed to see bright lines in any star which he has examined. . . . . I have had occasion to notice on more than one occasion that a stellar spectrum which is full of dark lines or bands may, when badly seen, give a very perfect illusion of bright lines; the dark lines escaping recognition as such, but producing their effect by making the parts of the spectrum most free from them shine out by contrast like a veritable chromospheric spectrum."

The method by which it was hoped to distinguish between bright background space is already explained. It was hasty to claim bright lines for numerous stars. The announcement should have awaited the completion of the series of observations. Credence for the statement without such a series cannot be asked, but it is asked that the result of the series be awaited.

(*d*) "And that though 'sometimes they shine with almost metallic brilliancy,' yet no previous observer has detected them."

The spectroscopic arrangement is considerably different from that usually employed. Although no assertion of the existence of the lines has reached me, there is at least one who has suspected them, as the following quotation shows :* "Two years ago (1876) I searched for indications of a large chromosphere in the case of *a Lyræ* and some other stars. I believe I had glimpses of bright lines at F and *b*, but if this discussion [between Huggins and Stone] had not arisen I should have still hesitated to mention this, as I had been hoping for an increase of optical power."

In closing one may perhaps draw attention to this fact, that the result is not at variance with our best knowledge of stellar constitution. Speaking of the lesson to be learned from T *Coronæ*, a recent writer says: "No clear dividing line can be drawn between stars and nebulæ, but that in what are called planetary nebulæ on the one side and in 'gaseous stars' (those giving a spectrum of bright lines) on the other, we meet with transitional forms serving to bridge the gap"† between the faintly lucent nebula and the highly-finished star, and among the stars themselves one may readily pursue every value of the ratio expressing the relation between the light from the stellar nucleus and from the stellar atmosphere. While the arrangement which will bring out the absorption lines will hide all but the brightest of the gaseous lines, the method just described is, I think, bringing out those lines which belong to the gaseous envelope.

* Note on Bright Lines in the Spectra of Stars and Nebulæ. By J. Norman Lockyer. Proc. Roy. Soc. Vol. 27, p. 50.

† History of Astronomy during the Nineteenth Century, Clerke, pp. 422–423.

## *Bands observed in the Spectra of Sun-spots at Stonyhurst Observatory.* By the Rev. A. Cortie, S.J.

(*Communicated by the Rev. S. J. Perry.*)

There are three kinds of bands which have been observed in the spectra of Sun-spots. The first, which is a certain fuzzy appearance surrounding the widened portions of the dark lines, has been very frequently seen, and is only a particular phase of the widening of the line. The second is an intensifying of the general absorption due to a Sun-spot in particular parts of the spectrum. The third is the appearance of real bands in the selective absorption due to a spot. The present paper contains some observations of each of these kinds of bands.

With regard to the hazy appearance or fuzziness surrounding a widened line, it is usually and most easily observed on the D lines, although not peculiar to them. In a spot in the S. F. quadrant of the Sun observed on November 15, 1883, the widening of all the lines, instead of a dark and distinct thickening of the same, presented the appearance of a penumbral shade at either side of the dark central line. But this haziness has been most markedly attached to the D lines on several occasions. Thus on September 29, 1884, and on January 14, 1886, these two lines were not only widened and fuzzy, but were also reversed in one portion of their length. Sometimes the haze exists surrounding the lines, while the lines themselves are not widened, as on October 2 and 3 of the present year in a small spot. In the part of the spectrum between D and C, Ångström gives a line as due to *Na* at 6160·23 a little more refrangible than a strong *Ca* line at 6160·40. This *Na* line is drawn as double in the maps of Fievez and Piazzi Smyth, and with good definition, and using a dispersion of twelve prisms, it has been usually so seen. This double is always remarkably widened in the spectra of spots, and, moreover, the widening is of the nature of the fuzzy band seen at times in connection with the D lines. If a moderate dispersion of six prisms be used, it appears as if the *Ca* line adjoining this faint double was considerably widened and displaced towards the violet. But on using a great dispersion the widening is seen to be principally due to these faint *Na* lines, although the thick *Ca* line is usually also affected. On June 25, 1885, and on January 14, 1886, the widened *Ca* line was seen running through the haze due to these *Na* lines. In the small spot of October 2 of the present year, the band due to these lines was at least one-tenth mètre in breadth. Finally it may be mentioned in connection with the D lines, that when the widening on the two sides is unequal, the balance is almost invariably in favour of the violet or more refrangible side of the lines.

The second kind of band is due to the intensifying of the general absorption in particular parts of the spectrum of Sun-spots. This phenomenon has only been observed on four occasions during the course of as many years of observation. On May 11, 1884, the general absorption of a large spot N F had a blurred appearance in the red end, and besides was so dark that it almost masked the selective absorption, rendering it very difficult of observation. The same appearance was seen on May 18 of the same year in a black spot S P. Again, on June 25, 1885, the lines about 6172·5 were masked by this blurring effect; and, finally, on February 6, 1886, the relative darkness of the general absorption in the red end was much more intense than in the rest of the spectrum. This last observation was made between 2 and 3 P.M. in a hazy sky. In the Greenwich observations of the great Sun-spot of November 19, 1882, it is noted that "the general absorption was not uniform; here and there there were ill-defined patches, noticeably darker than the rest of the spectrum." Again, although Prof. Young, using a Rowland grating attached to a 23-inch equatorial, has succeeded in resolving even the band of continuous shade, due to a Sun-spot, into a series of fine dark lines with bright spaces (*Amer. Jour. Science*, vol. xxvi. November 1883), yet he remarks that "in the red, even with the highest dispersion, and under the most favourable circumstances of vision, the spot-spectrum appears simply as a continuous shade, crossed here and there by widened and darkened lines."

The last of the three kinds, into which we have divided this phenomenon of spot-bands, is perhaps the most important of all, because of its connection with the selective absorption of Sun-spots. The first recorded observations of these bands are those of Professor Young (*Nature*, December 12, 1872). With regard to their interpretation he states that "they would seem to point to such a reduction of temperature over the spot-nucleus as permits the formation of gaseous compounds by elements elsewhere dissociated." In the Greenwich Spectroscopic and Photographic Results for the years 1880–83 many observations of similar bands are recorded in the portion of the spectrum from D to F. At Stonyhurst the spot-spectrum is observed from D to B. The spectroscope employed is an automatic instrument by Browning, and the dispersion generally used is one of twelve prisms of 60°. Perhaps the region richest in the various phenomena of the spectra of Sun-spots in this part of the spectrum is that included between λ 6370·0 and C. Nine of the lines have coincident bright lines in the chromospheric spectrum as mapped by Young, and there are four dark basic lines. It is in this portion that the spot-bands have been most frequently seen, and two of them have been selected for particular attention and study. The bands were first noticed on February 28, 1885, especially a broad one lying between the lines λ 6438·35 and 6449·29, and they have been seen on eight

subsequent occasions. The number of bands so far reckoned is nine. Of these the two more particularly studied are situated the one near λ 6380·0 and the other at λ 6383, the positions being fixed by accompanying lines, and being most probably correct to within one-tenth mètre. On May 26 of the present year these two bands were most distinct in a spot of regular outline. The first adjoined the line λ 6379·99 on its less refrangible side. The second had no line at its edges but was diffused in appearance, although its tint was somewhat intensified towards the red end. The general appearance of these bands resembled a fluted spectrum, and some very faint lines could be traced from them into the ordinary spectrum. These two bands were again examined most carefully on July 2nd and 4th of the present year in magnificent definition. The general absorption given by the spot was one with well-defined edges. On the former of these dates the spot-band at λ 6379·99 was joined on to the line as observed on May 26. But on the 4th, when the general absorption was less intense, it no longer adjoined the line, but was clearly separated from it. Moreover, its appearance had altered, for it seemed to be formed by two or three lines very greatly widened. The companion band also seemed to be composed of three lines similarly affected. But these bands or groups of lines were due to the spot alone, for no trace of them could be detected when the spot was removed from the slit, and they stood out most clearly and distinctly in the darkest part of the umbra. On the 7th, when the spot had approached the limb, none of the bands were so distinct as formerly, although the definition was equally good. Yet they were visible in the spot, and nowhere else. In the small spot of October 2nd and 3rd no bands at all could be detected in the region between λ 6379·99 and C. On the 3rd, however, the lines at 6242·6 (A°) and 6305·0 (Fievez) had a banded appearance on their more refrangible side, possibly due to a displacement in that direction. It may be noted, however, that this line 6305·0 corresponds to a line in Young's diagram (*loc. cit.*) marked at K 796·2, which is depicted as enormously widened.

Finally, with regard to the two bands selected as typical of this third class, this must be remarked, that they occur in a portion of the spectrum in which Ångström marks no line, and in which the very great dispersion employed by Fievez and Piazzi Smyth gave in the first case two, and in the second three faint lines, about the position of the second band. Coincident with the first band there is absolutely no dark line mapped, which is true also for the bands between λ 6438·35 and λ 6449·29. This, coupled with the fact that they appear only in Sun-spots, and there are most intense in the umbra, shows them to belong exclusively to Sun-spot spectra. They are a phenomenon altogether distinct from the ordinary widened, or darkened, or obliterated line of such spectra. From fifteen to twenty such bands are recorded in the Greenwich observations,

nine have been seen at Stonyhurst, and always in the same positions. Even should higher dispersion resolve them into lines, such clusters of greatly widened lines occurring at certain definite positions in the spectra of some Sun-spots is a remarkable phenomenon well deserving the closest attention.

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## *Note on Photographs of Stars in Cygnus taken in August* 1886. By Isaac Roberts.

The negatives which I now exhibit were taken with my 20-inch Reflector on the nights of August 17, 23, 24, and 25 this year, and they represent parts of the constellation *Cygnus*, corresponding with those photographed by MM. Henry with their 13-inch refractor in June and August 1885, copies of which have been presented to the Society as well as to some of the Fellows.

The celestial position of the centre of each plate is as follows:

| | | h m | | ° ' |
|---|---|---|---|---|
| No. 1 | R.A. | 21 2 | Decl. | 35 12 |
| 3 | " | [illegible] 45 | " | 35 30 |
| 4 | " | [illegible] 55 | " | 37 45 |
| 5 | " | 20 4 | " | 35 30 |

The enlargements have been made to the scale corresponding with that adopted by MM. Henry so as to facilitate comparisons between them. The time of exposure, namely, 60 minutes, is common to all the photographs.

If we compare these plates with those by MM. Henry there are striking differences observable in the sharpness of the margins of the star discs, in the density of the images, and in the number of stars photographed in 60 minutes by the two instruments respectively.

In the Henry plates the margins of the stars are remarkably sharp and clearly defined. The brightness or density of the images also, whether the stars are of the second or of the fifteenth magnitude, is equal in all without perceptible gradation. The reflector, on the contrary, shows the margins somewhat undefined, and the stars of the first to the third magnitude show prominently diffraction effects around them. Not less noticeable is the gradation of the light of the stars between the brightest and the faintest shown on the plates; the gradations are such that the stars are ultimately lost in the colour of the background or film, and to define their magnitudes will severely tax the powers of classification.

In drawing inferences from the relative numbers of the stars

photographed by the two instruments in sixty minutes, it must be remembered that besides the difference between them in principle and aperture, there may be difference in the sensitiveness of the plates used, also difference in the atmospheric conditions when the photographs were taken as well as difference in the method of developing the images; but, subject to these reservations, we may, in the absence of more exact methods, make approximate comparisons by counting the number of stars on a given area, such as a square inch, on the enlarged photographs respectively. In this manner I counted on one of the reflector photographs 109, 93, and 70, or an average of 91 stars on one square inch. The numbers on the corresponding areas on the refractor photograph were 59, 64, and 41, or an average of 55 stars on one square inch. It therefore appears that the reflector has over the refractor the advantage of number in the average ratio of nearly two stars to one.

In view of others entering upon the work of photographing the stars, and to save them much waste of time and resources, it would be desirable to make comparisons between the relative efficiency of existing refractors and reflectors as instruments for photographing.

The comparisons might be made in some such manner as the following:

1stly. A sufficient number of photographic dry plates should be obtained from some reliable maker. They should be made from one uniform admixture of emulsion, and the plates distributed among those who would engage in the enquiry.

2ndly. A given number, such as ten, of the plates should be exposed for thirty minutes each on ten different clear nights (one plate each night) upon such sky spaces as may be determined.

3rdly. The plates should be developed by the same chemical formulæ with an immersion in the developer, say of five minutes.

4thly. The number of stars upon each plate should be counted and the density of the images noted.

The result would at least be some guide to those who intend to engage in photographing the stars, to enable them to choose their instruments and to compare their work afterwards. In addition to the information thus to be obtained, a report upon the driving-clock used in the experiments should be prepared, and its errors given during each exposure of the plates. An accurate and reliable driving-clock and gearing are absolutely essential in star photography, for any appreciable error would distort the star discs, and so prevent accurate micrometrical measurements of their relative positions being made.

## *Note on two Photographs of the Nebulæ in the Pleiades taken in October* 1886. By Isaac Roberts.

On the night of October 23 (last month), I had an opportunity of taking a photograph of the *Pleiades*, and intended to expose the plate for three hours so as to be able to compare the result with that obtained by MM. Henry, but clouds caused me to stop the exposure after eighty-nine minutes. The plate when developed showed clearly that the stars *Alcyone*, *Maja*, *Electra*, and *Merope* are surrounded by nebulæ, indications of which about three of the stars are shown on MM. Henry's chart, which is published in the *Annales de l'Observatoire de Paris.*

On the following night (the 24th) I exposed another plate for three hours, which, after development, showed that not only are the stars which I have just named surrounded by nebulæ, but that the nebulosity extends in streamers and fleecy masses, till it seems almost to fill the spaces between the stars, and to extend far beyond them. It suggests the probability that these principal stars in the *Pleiades*, together with many of the stars around them, are involved either directly or else in sight alignment with one vast nebula. The negatives and the enlargements to six diameters, which I now exhibit, will enable you to appreciate and to form your own judgment as to the credibility of the evidence upon which these inferences rest, and I await with watchfulness for a clear interval which will enable me to try an exposure of *five hours* in order to obtain more light upon the subject.

The star discs upon the photographs are somewhat deformed by refraction and uncorrected instrumental movements, but I think you will not have much difficulty in mentally making the corrections necessary to form accurate judgment; and I anticipate being able to obviate this slight distortion in future exposures.

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## *The Orbit of Comet II.*, 1883, *discovered by Mr. Ross.* By Lieut.-General J. F. Tennant, R.E., F.R.S.

Some considerable time ago I made some efforts to get a satisfactory orbit for this comet, but circumstances were unfavourable and I had to give it up. More recently I was induced to take it up to see if there were any real departure from a Parabolic Orbit such as Mr. Bryant found, or whether his result was only due to the selection he had made of observations. My conclusion was that there was no real justification for departing from the parabola. Then I found that the compilers of the *Annuaire du Bureau des Longitudes* had adopted Mr. Bryant's

results, and I made some further calculations. I now offer my results for publication lest what I think a mistake should pass unnoticed.

Starting with Mr. Tebbutt's orbit as an approximation, I computed an ephemeris from January 10 to February 6, 1884, for each Greenwich noon, and with this compared the whole of the observations at Melbourne,* Windsor, and Madras. The Melbourne observation of January 17 is affected with considerable error, and I was obliged to reject it. The mean of the observations at Madras on January 26, and the observations at Madras on January 30, at Melbourne on February 1, and Windsor on February 2, are somewhat discordant, but I have not excluded them, as I did not think they would materially affect my result. I then proceeded to obtain normal places, and found the error of my ephemeris to be

| | | | |
|---|---|---|---|
| On Jan. 17·0 | in R.A. $+51''\!\cdot\!4$ | in Decl. | $-34''\!\cdot\!3$ |
| 26·5 | $+39\cdot8$ | | $-26\cdot0$ |
| 30·0 | $+29\cdot8$ | | $-24\cdot0$ |

From the places found by applying these corrections to the ephemeris I computed a parabolic orbit with the following result:

T = Perihelion Passage 1883, Dec. 25·31928

$\log q = 9\cdot4938146$

$$\left.\begin{array}{l} \pi = \;\;43^\circ\;30'\;48''\!\cdot\!5 \\ \Omega = 264\;\;33\;\;13\cdot5 \\ L = 114\;\;59\;\;03\cdot1 \end{array}\right\}\text{Mean Equinox, Jan. 0, 1884}$$

which give at the middle date

$$\lambda_c - \lambda_o = +11''\!\cdot\!2$$
$$\beta_c - \beta_o = -\;\;9\cdot6$$

a result larger than I had anticipated from the errors of the ephemeris at the selected times.

By forming equations of condition for the effects of small changes in the elements, I obtained the following elliptic orbit:

T = 1883, Dec. 25·320145

$\log q = 9\cdot4899874$

$e = 0\cdot9980441$

$$\left.\begin{array}{l} \pi = \;\;43^\circ\;33'\;16''\!\cdot\!8 \\ \Omega = 264\;\;51\;\;04\cdot0 \\ L = 115\;\;03\;\;44\cdot3 \end{array}\right\}\text{Mean Equinox, Jan. 0, 1884.}$$

* I have used the corrected observations in the "Astronomische Nachrichten." Those published in the *Monthly Notices* have great error.

The period would be 1,986 years, but, of course, the deduction of so long a period from such data is not to be considered as giving it any certainty.

Having the equations of condition I proceeded to see what would be the most probable parabola from the normal places, and found

$$T = 1883,\ \text{Dec. } 25{\cdot}319222$$
$$\log q = 9{\cdot}49389953$$
$$\left.\begin{aligned} \pi &= \phantom{0}43^{\circ}\ 30'\ 40''{\cdot}4 \\ \Omega &= 264\ \ 32\ \ 54{\cdot}4 \\ L &= 114\ \ 39\ \ 01{\cdot}9 \end{aligned}\right\}\ \text{Equinox as before.}$$

The errors at the times of the normal places, as obtained from the equations of condition.

| | | | | |
|---|---|---|---|---|
| C–O at 1st date | in R.A. | $+4''{\cdot}43$ | in Decl. | $+1''{\cdot}74$ |
| 2nd | | $-7{\cdot}98$ | | $+7{\cdot}42$ |
| 3rd | | $+2{\cdot}49$ | | $-1{\cdot}76$ |

leading to a probable error of $\pm 4''{\cdot}8$ in the determination of one element, which seems possible enough when one looks at the individual observations. But it would have been preferable to give more weight to the middle place, as the observations about the middle of the apparition are the best.

On the whole I think that we have no sufficient data for assigning elliptic elements, and that the parabola last given is about as good as any which can be deduced from the observations, though the real orbit may be an ellipse of long period.

## *Observations of Comet f 1886 (Barnard), made at the Royal Observatory, Greenwich.*

*(Communicated by the Astronomer Royal.)*

The observations were made with the East or Sheepshanks Equatorial, aperture 6·7 inches, by taking transits over two cross-wires at right angles to each other, and each inclined 45° to the parallel of Declination.

*Comet f 1886.*

| 1886. | Greenwich Mean Solar Time. h m s | Observer. | ☄ − ✱ R.A. m s | Corr. for Par. and Refract. in R.A. s | ☄ − ✱ N.P.D. ′ ″ | Corr. for Par. and Refract. in N.P.D. ″ | No. of Comp. | Apparent R.A. h m s | Apparent N.P.D. ° ′ ″ | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|
| Nov. 2 | 16 8 24 | A.D. | −1 18·89 | −0·14 | +14 15·0 | −2·1 | 6 | 11 53 44·02 | 82 59 24·6 | *a* |
| 4 | 17 0 9 | H. | +0 5·40 | −0·22 | −6 32·5 | −4·9 | 1 | | | *b* |
| 4 | 17 37 4 | | +0 37·63 | −0·18 | +1 59·6 | −4·4 | 3 | | | *c* |
| 5 | 16 47 10 | T. | +1 47·77 | −0·23 | −6 34·9 | −4·9 | 3 | | | *d* |
| 5 | 16 48 23 | | +1 21·90 | −0·21 | − 44·6 | −4·5 | 4 | 12 7 4·67 | 81 59 5·3 | *e* |
| 7 | 18 0 0 | L. | +2 31·00 | −0·17 | −3 8·5 | −4·8 | 10 | 12 15 11·02 | 81 15 2·0 | *f* |

*Mean Places of Comparison Stars.*

| Star's Name. | R.A. 1886·0. h m s | N.P.D. 1886·0. ° ′ ″ | Authority. |
|---|---|---|---|
| (*a*) π Virginis | 11 57 1·87 | 82 45 0·5 | Nautical Almanac |
| (*b*) Arg. Z. + 7° − 2515 | 12 1 41·9 | 82 27·0 | Bonn Obs. vol. iii. |
| (*c*) Arg. Z. + 7° − 2514 | 12 1 20·6 | 82 16·3 | Bonn Obs. vol. iii. |
| (*d*) Arg. Z. + 8° − 2575 | 12 5 14·6 | 82 6·4 | Bonn Obs. vol. iii. |
| (*e*) W.B. XII. 49 | 12 5 41·95 | 81 59 45·0 | Schjellerup |
| (*f*) W.B. XII. 164 | 12 12 39·16 | 81 18 5·8 | Schjellerup |

*Notes.*

November 2.—Comet bright, with nucleus and faint tail. November 5.—Sky hazy. Comet bright, with nucleus. November 7.—Comet very bright, stellar nucleus.

The observations are corrected for Parallax and Refraction. The initials A.D., T., L., and H. are those of Mr. Downing, Mr. Thackeray, Mr. Lewis, and Mr. Hollis respectively.

*Royal Observatory, Greenwich:*
1886, *November* 11.

## *Observations of Comets made at Mr. Wigglesworth's Observatory with the 15·5-inch Cooke Refractor.* By J. G. Lohse.

### *Comet 1885 a, Barnard.*

| Date | Scarborough Mean Time | Δα ☄ − ★ | Δδ | α ☄ | δ ☄ | Num. of Comp. |
|---|---|---|---|---|---|---|
| 1885 | h m s | s | | h m s | | |
| July 17 | 11 51 42 | + 25·27 | — | 17 3 51·79 | — | 7 |

### *Comet 1885 d, Fabry.*

| Date | Scarborough Mean Time | Δα ☄ − ★ | Δδ | α ☄ | δ ☄ | Num. of Comp. |
|---|---|---|---|---|---|---|
| 1885 | h m s | s | ′ ″ | h m s | ° ′ ″ | |
| Dec. 7 | 8 37 23 | − 19·03 | +2 4·8 | 0 25 9·54 | +20 52 43·8 | 5 |
| „ 24 | 8 41 2 | + 23·38 | +1 23·6 | 23 54 16·75 | +20 40 52·1 | 6,6 |
| „ „ | 9 12 40 | + 21·54 | +1 22·5 | 23 54 14·91 | +20 40 51·0 | 3 |
| „ 28 | 7 35 15 | − 5·26 | +2 13·6 | 23 48 58·95 | +20 44 20·4 | 7 |

### *Comet 1885 e, Barnard.*

| Date | Scarborough Mean Time | Δα ☄ − ★ | Δδ | α ☄ | δ ☄ | Num. of Comp. |
|---|---|---|---|---|---|---|
| 1885 | h m s | m s | ′ ″ | h m s | ° ′ ″ | |
| Dec. 6 | 11 53 53 | − 43·48 | −1 13·9 | 4 14 57·79 | + 4 55 56·4 | 8,8 |
| „ 7 | 12 24 15 | − 20·87 | −6 21·3 | 4 12 29·90 | + 5 3 53·2 | 4 |
| „ 10 | 11 11 12 | − 3·56 | +7 38·2 | 4 5 13·27 | + 5 21 1·5 | 9 |
| „ 13 | 12 27 7 | + 26·98 | + 19·6 | 3 57 33·46 | + 5 40 31·6 | 8 |
| „ 28 | 11 45 0 | −1 32·55 | + 48·5 | 3 19 54·70 | + 7 41 53·1 | 5,5 |
| 1886 Jan. 2 | 10 26 45 | − 22·95 | −3 59·7 | 3 8 13·97 | + 8 29 59·7 | 5 |

### *Adopted Mean Places of Comparison Stars for 1885·0 and 1886·0.*

| | α | Redn. | δ | Redn. | Authority. |
|---|---|---|---|---|---|
| 1885 | h m s | s | ° ′ ″ | ″ | |
| July 17 | 17 3 26·57 | +2·95 | −10 22 15·8 | + 7·9 | B.-W., 17h 3. |
| Dec. 7 | 0 25 25·13 | +3·44 | +20 50 14·0 | +25·0 | 8·5 mag. ★ connected with B.-W., 0h (838 + 840)/2 |
| | 0 33 52·56 | | +20 48 27·1 | | |
| 24 | 23 53 50·41 | +2·96 | +20 39 2·9 | +25·6 | B.-W., 23h 1096. |
| 28 | 23 49 1·35 | +2·86 | +20 41 41·4 | +25·4 | 9 mag. ★ connected with B.B. VI. + 20° 5397. |
| | 23 50 12·68 | | +20 42 30·3 | | |
| Dec. 6 | 4 15 37·16 | +4·11 | + 4 57 8·9 | + 1·4 | 11 mag. ★ connected with Glasg. Cat. 1067. |
| | 4 19 50·69 | | + 4 53 10·1 | | |
| 7 | 4 12 46·65 | +4·12 | + 5 10 12·9 | + 1·6 | 10 mag. ★ connected with Glasg. Cat. 992. |
| | 4 5 12·71 | | + 5 13 21·2 | | |
| 10 | 4 5 12·71 | +4·12 | + 5 13 21·2 | + 2·1 | Do. |
| 13 | 3 57 2·35 | +4·13 | + 5 40 9·3 | + 2·7 | ν Tauri, Berliner Jahrb. |
| 28 | 3 21 23·23 | +4·02 | + 7 40 59·1 | + 5·5 | B.B. VI + 7° 510. |
| 1886 Jan. 2 | 3 8 36·20 | +0·72 | + 8 34 6·4 | − 7·0 | Ast. Nach. 2709 [¼ (Sant. + 8° 40 + Schj. 927–28 + Glasg. 748)]. |

*Mr. Wigglesworth's Observatory,*
*Scarborough:* 10 *Nov.*, 1886.

*Notes.*

July 17.—The comet is faint and round; it becomes gradually brighter towards the middle, but has no real nucleus. It is much fainter than on July 14; it was well seen on that day, but clouds came on before an observation could be obtained.

December 24.—Comet Fabry is round and has a stellar nucleus; it is about 2′ in diameter, but still faint. Clouds lit up by the Moon were troublesome.

December 6.—Comet Barnard is faint and small. The coma extends farther on the following side than in other directions. The central bright part appears granulated, and equals in brightness about an 11th mag. star. The diameter of the comet is 4 to 5 seconds in time.

December 10.—The comet is decidedly more extended on the following side, and about of the same brightness as on December 6 and 7. The diameter is about 7 seconds.

December 28.—The comet was often barely visible through the faint clouds passing. At intervals it was snowing and very stormy. The comet is elongated on the following side, and the nucleus is brighter than that of comet *d*, but the latter seems to be the larger one, though the difference is very small.

January 2.—The sky being hazy the comet appeared very faint.

The observations were made with a wire micrometer by Merz, kindly lent by Lord Crawford. Only for the first observation a transit micrometer, with a set of fixed wires, was used.

Refraction has always been taken into account.

For the catalogue places of most of the comparison stars I am indebted to Dr. Copeland.

The co-ordinates of the Observatory have been taken from the 6-inch Survey Map, and are:

Longitude of Observatory $= 1^{m} 38^{s}.9$ west of Greenwich.
Latitude ,, $= +54^{\circ} 16' 30''$.

*Observations of Phenomena of Jupiter's Satellites, made at Windsor, New South Wales, in the year* 1886.
By John Tebbutt.

I send herewith my observations of phenomena of *Jupiter's* satellites during the current year. The Fellows will, doubtless, be glad to learn that I have added to my Observatory appliances a fine Equatorial Refractor of 8 inches aperture, with which I propose to continue not only the observations of the eclipses but also those of the transits and occultations. My telescope of 4½ inches aperture was hardly equal to the work of observing the two last-mentioned phenomena. I also intend to follow more extensively the work of double star observation. The large Equatorial, which is driven by clockwork, was constructed by Grubb, of Dublin, for the late Dr. Bone, of Castlemaine, Victoria, and its object-glass, both from Mr. Ellery's and my own short experience with it, appears to be one of great excellence. In the accompanying table the telescope with which each observation was made is distinguished by the initial letter of the maker's name. C. and G. denote the Cooke and Grubb Equatorials of 4½ and 8 inches aperture respectively.

*Phenomena of Jupiter's Satellites.*

| Day of Obs. | Sat. | Phenomena. | Phase. | Telescope. | Power. | Windsor Mean Time. | Correction to N. Almanac. |
|---|---|---|---|---|---|---|---|
| | | | | | | h m s | m s |
| March 28 | I. | Ecl. R. | First seen | C. | 180 | 13 30 15·8 | + 1 26·0 |
| 28 | I. | „ „ | Full brightness | „ | „ | 13 31 37·1 | |
| 28 | IV. | „ D. | Last seen | „ | 130 | 14 38 32·9 | −15 34·9 |
| 28 | IV. | Ecl. R. | First seen | „ | „ | 16 28 4·7 | + 8 53·9 |
| April 1 | III. | „ „ | First seen | „ | 180 | 6 55 19·2 | + 1 13·4 |
| 1 | III. | „ „ | Full brightness | „ | „ | 7 0 43·4 | |
| 4 | I. | „ „ | First seen | „ | „ | 15 22 48·2 | + 0 8·4 |
| 4 | I. | „ „ | Full brightness | „ | „ | 15 25 49·2 | |
| 22 | I. | „ „ | First seen | „ | „ | 8 7 55·1 | + 0 7·3 |
| 22 | I. | „ „ | Full brightness | „ | „ | 8 10 6·2 | |
| 24 | II. | „ „ | First seen | „ | „ | 6 36 12·2 | − 0 13·6 |

| Day of Obs. | | Sat. | Phenomena. | Phase. | Telescope. | Power. | Windsor Mean Time. h m s | Correction to N. Almanac. m s |
|---|---|---|---|---|---|---|---|---|
| April | 24 | II. | Ecl. R. | Full brightness | C. | 180 | 6 38 7·9 | |
| May | 1 | II. | " " | First seen | " | " | 9 13 13·4 | − 0 2·4 |
| | 1 | II. | " " | Full brightness | " | " | 9 15 22·1 | |
| | 8 | I. | " " | First seen | " | 40 | 6 25 0·8 | − 0 2·0 |
| | 8 | II. | " " | First seen | " | " | 11 49 49·6 | − 0 15·2 |
| | 8 | II. | " " | Full brightness | " | " | 11 52 37·1 | |
| | 14 | III. | " " | First seen | " | " | 6 40 45·5 | − 0 14·3 |
| | 14 | III. | " " | Full brightness | " | " | 6 46 55·9 | |
| | 15 | I. | " " | First seen | " | " | 8 19 42·2 | + 0 9·4 |
| | 21 | III. | " D. | Fading | " | " | 7 59 12·0 | |
| | 21 | III. | " " | Last seen | " | " | 8 4 1·7 | + 3 48·9 |
| | 21 | III. | " R. | First seen | " | " | 10 39 18·3 | + 0 5·5 |
| | 21 | III. | " " | Full brightness | " | " | 10 44 18·5 | |
| | 22 | I. | Occ. D. | Ext. contact | G. | 350 | 6 51 41·7 | |
| | 22 | I. | " " | Total disapp. | " | " | 6 55 7·2 | |
| | 22 | I. | Ecl. R. | First seen | " | 225 | 10 13 51·1 | − 0 16·7 |
| | 22 | I. | " " | Full brightness | " | " | 10 15 38·8 | |
| | 31 | I. | " " | First seen | C. | 40 | 6 37 17·7 | − 0 8·1 |
| June | 25 | II. | Tr. Ingr. | Ext. contact | G. | 170 | 5 40 14·3 | |
| | 25 | II. | " " | Int. contact | " | " | 5 44 48·5 | |
| | 25 | II. | " Egr. | Int. contact | " | " | 8 24 50·9 | |

| Day of Obs. | | Sat. | Phenomena. | Phase. | Telescope. | Power. | Windsor Mean Time. h m s | Correction to N. Almanac. m s |
|---|---|---|---|---|---|---|---|---|
| June | 25 | II. | Tr. Egr. | Ext. contact | G. | 170 | 8 29 31·2 | |
| | 26 | III. | Ecl. R. | First seen | ,, | ,, | 6 29 16·7 | − 0 48·1 |
| | 26 | III. | ,, ,, | Full brightness | ,, | ,, | 6 34 21·9 | |
| | 27 | II. | ,, ,, | First seen | ,, | ,, | 6 4 50·6 | − 0 44·2 |
| | 29 | I. | Tr. Ingr. | Ext. contact | ,, | ,, | 8 8 41·8 | |
| | 29 | I. | ,, ,, | Int. contact | ,, | ,, | 8 11 26·4 | |
| July | 3 | III. | Ecl. D. | Fading | ,, | ,, | 7 56 12·9 | |
| | 3 | III. | ,, ,, | Last seen | ,, | ,, | 8 2 4·9 | + 5 25·1 |
| | 4 | II. | ,, R. | First seen | ,, | ,, | 8 41 11·1 | − 0 19·7 |
| | 4 | II. | ,, ,, | Full brightness | ,, | ,, | 8 43 14·2 | |
| | 10 | III. | Occ. D. | Ext. contact | ,, | 225 | 6 46 2·4 | |
| | 10 | III. | ,, ,, | Total disapp. | ,, | ,, | 6 55 55·7 | |
| | 11 | II. | ,, ,, | Ext. contact | ,, | ,, | 6 7 5·0 | |
| | 11 | II. | ,, ,, | Total disapp. | ,, | ,, | 6 11 39·2 | |
| | 28 | III. | Tr. Ingr. | Ext. contact | ,, | 175 | 5 15 22·2 | |
| | 28 | III. | ,, ,, | Int. contact | ,, | ,, | 5 21 41·2 | |
| Aug. | 8 | III. | Ecl. R. | First seen | ,, | 170 | 6 19 53·9 | − 0 4·9 |
| | 8 | III. | ,, ,, | Full brightness | ,, | ,, | 6 23 14·8 | |
| | 8 | I. | ,, ,, | First seen | ,, | ,, | 7 17 5·4 | + 0 4·6 |
| | 8 | I. | ,, ,, | Full brightness | ,, | ,, | 7 19 5·5 | |
| | 24 | I. | ,, ,, | First seen | ,, | 130 | 5 36 0·0 | + 0 49·2 |

*Remarks.*

March 28.—Definition of Satellite I. not good; observation probably somewhat late. IV. growing faint at $14^h\ 37^m\ 26^s$, and I thought I could just glimpse it again at $14^h\ 39^m\ 20^s.8$. Satellite first noted at $16^h\ 28^m\ 4^s.7$, but I was quite certain of it 57 seconds later.

April 1.—Fair definition; satellite suspected 32 seconds before recorded time.

April 4.—Clear, but definition bad and images tremulous.

April 22.—Good definition and observation.

April 24.—Beautifully clear and definition excellent; very good observation.

May 1.—Images steady and definition excellent; good observation.

May 8.—Images steady and definition good; beautifully clear. The observation of the first appearance of II. probably rather late.

May 14.—Beautifully clear and definition good.

May 15.—Good definition, but sky overspread with thin cloud.

May 21.—Beautifully clear. Definition very good at disappearance, but images rather tremulous at reappearance. Defalcation of light marked at $7^h\ 59^m\ 45^s.9$. Satellite suspected a few seconds before recorded time of first appearance.

May 22.—Definition excellent throughout.

May 31.—Beautifully clear and definition good.

June 25.—Definition fair at ingress, but not so good at egress.

June 26.—Images steady, and definition unusually good.

June 27.—Beautifully clear, images steady and well defined; good observation.

June 29.—Bad definition.

July 3.—Definition excellent, with clear sky.

July 4.—Clear, but with bad definition.

July 10.—Fair definition.

July 11.—Clear; definition fair, but images tremulous.

July 28.—Definition not good enough for a higher power. Satellite barely visible as a light spot at $5^h\ 29^m\ 10^s$, and quite invisible at $5^h\ 53^m\ 36^s$. At $6^h\ 32^m\ 30^s$ pretty conspicuous as a dark, not black, hazy spot; it had then nearly reached mid-transit, and was rather more than half the planet's semi-diameter distant from the planet's centre. Clouds prevented further observation.

August 8.—Beautifully clear, but with poor definition. Satellite III. suspected 10 seconds before recorded time of first appearance. Image of I. tremulous, with bad definition.

August 24.—Beautifully clear, but twilight very strong. Sun's upper limb disappeared behind the horizon $6^m\ 53^s$ before the recorded time of reappearance. Image steady and definition good.

*Windsor, N.S. Wales:* 1886, *Sept.* 28.

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## *Newall's Occulter.* By R. S. Newall, F.R.S.

I lately designed, and had made by a clever local optician, an addition to the eyepiece of my telescope, which I find of the greatest advantage in examining the satellites of planets and multiple stars.

My idea was to produce an instrument exactly the reverse of Dawes's solar eyepiece; that is, to interpose a screen which shall shut off the bright object, and thus allow of the faint companions being more easily seen, and, at the same time, the

apparatus must be simple and capable of easy manipulation and adjustment.

I had my eyepieces each fitted with a *stop*, that is, a piece of tube the same diameter as the adapter, into which the eyepiece fits, and the stop is cut of such length that when the eyepiece is pushed in it shall be in the focus suited to my sight, so that I have no trouble in adjusting.

The occulter is a ring of brass, about a quarter of an inch thick and three-quarters broad. It slips stiffly on to the eyepiece as shown in the accompanying drawing. The ring is bored with three holes, as in the section, and into each is fitted an ivory sphere, three-eighths of an inch in diameter. They are held in place by brass springs, which have a quarter-inch hole in each, to admit of the movement in any direction of a small platinum wire, which passes through the sphere. On one end of the wire is a disc, and on the other a small button or handle.

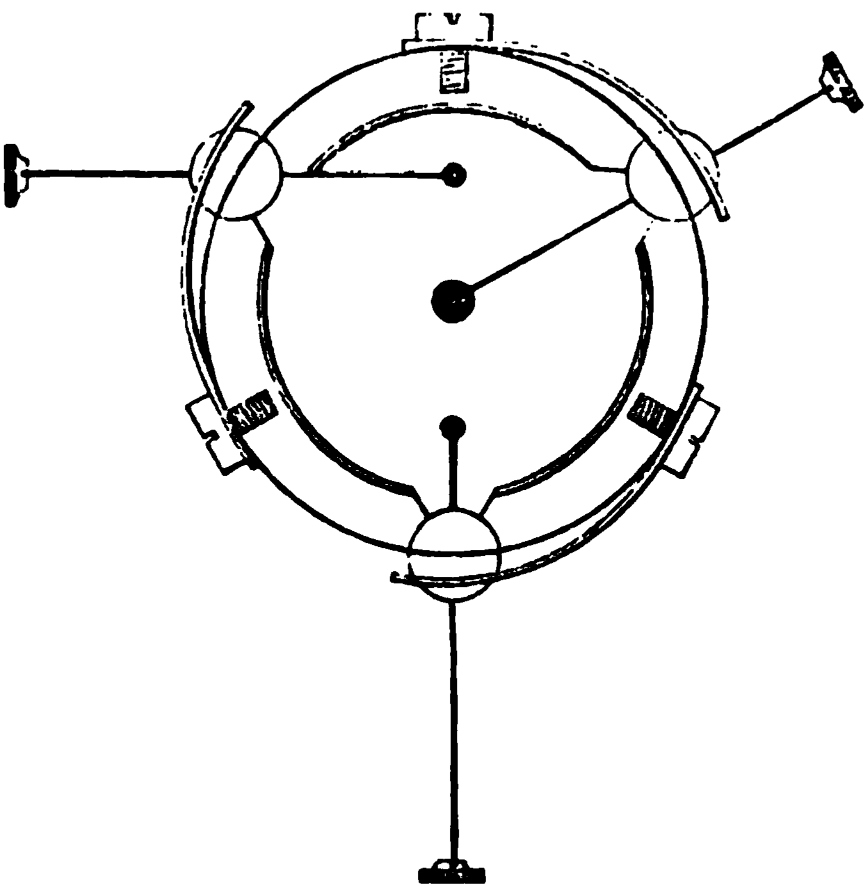

Fig. 1.

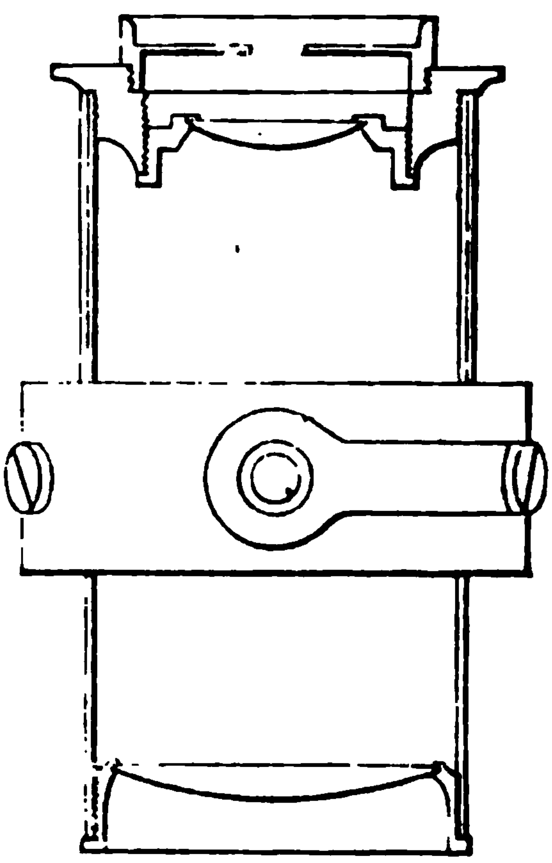

Fig. 2.

By these means the discs may be placed in any required position to eclipse the object, or they may be pushed to one side, so as to be entirely out of view; and when drawn back up to the ivory sphere the ring can be slipped off the tube, and the eyepiece is as it was, having only three holes in it corresponding to those in the ring. The centres of these holes are, of course, in the plane of the focus of the eye-lens, but the spheres allow of the discs being placed out of focus, which is sometimes of advantage. One disc would be quite enough for most work, but a spare one or two may be convenient occasionally, so I made mine with three discs slightly varying in size.

*November* 8, 1886.

## *Distribution of Meteor Streams.* By W. F. Denning.

I recently compiled a general catalogue of all the meteor streams recorded in the various publications which I collected together for the purpose. These include the observations or reductions of Backhouse, Bártfay, Corder, Denning, Denza, Greg, Gruber, Herschel, Heis, Kobold, Konkoly, Kövesligethy, Maggi, Neumayer, Sawyer, Schiaparelli, Schmidt, Serpieri, Tupman, Weiss, Zezioli, and many other minor contributors.

Mr. Greg's last Catalogue of 1876 was based on 850 radiants deduced from 15,000 catalogued meteors. At the present time we have 3,035 radiants, derived from more than 82,000 meteors. There has been an enormous increase in these observations during the last ten years.

Upon analysing all the positions, I find they exhibit a very unequal distribution amongst the constellations, a fact which is unquestionably due, partly to real differences, and, in a less degree, to the relatively excessive observations accumulated in certain months of the year. In Right Ascension the 3,035 radiant points are situated as follows:

| R.A. ° | | ° | Radiants. | Percentage. | R.A. ° | | ° | Radiants. | Percentage. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | to | 30 | 378 | 12·4 | 181 | to | 210 | 147 | 4·8 |
| 31 | „ | 60 | 449 | 14·8 | 211 | „ | 240 | 186 | 6·1 |
| 61 | „ | 90 | 315 | 10·3 | 241 | „ | 270 | 217 | 7·2 |
| 91 | „ | 120 | 229 | 7·6 | 271 | „ | 300 | 254 | 8·4 |
| 121 | „ | 150 | 192 | 6·3 | 301 | „ | 330 | 243 | 8·0 |
| 151 | „ | 180 | 142 | 4·7 | 331 | „ | 0 | 283 | 9·3 |

The meteor streams cluster in greatest abundance between 1° and 60° of R.A. This is a fact irrespective of the cometary showers of Andromedes (Nov. 27) and Perseids (Aug. 10), which fall in this region, and might be supposed to have induced the singular condensation referred to. The zone, following it from 61° to 90°, shows a great decline, notwithstanding it includes the Orionids (Oct. 17–20), and the mass of showers originating in *Auriga*, *Camelopardus*, and the eastern quarter of *Taurus*. And the zone, 331° to 0° preceding the region of maximum, though rich in Aquariads, Pegasids, Lacertids, and Cepheids, exhibits a great deficiency as compared with it. The excess, so decided in character, between 1° and 60° is distinctly to be attributed to the Cassiopeïds, $\alpha$, $\beta$, and $\gamma$ Andromedes, Arietids, Muscids, $\alpha$ and $\beta$ Perseids, Taurids, &c., which, combined with the cometary showers of Andromedes and Perseids, swell the aggregate number to an abnormal figure.

The minimum proportion of showers is clearly indicated

between 151° and 210° R.A., which does not much exceed one-third of those grouped between 1° and 60°, the relative figures being 289 and 827.

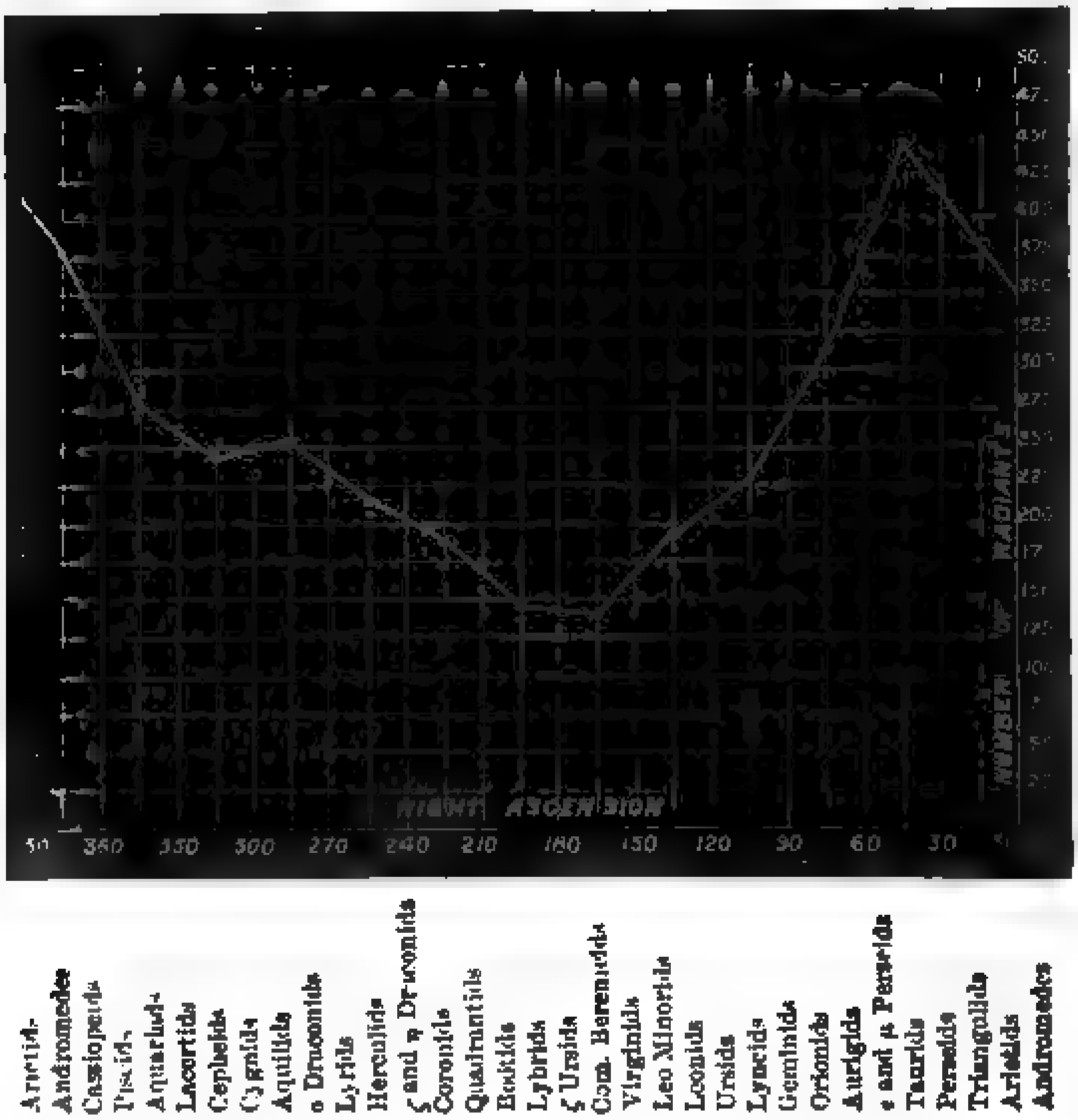


Fig. I.—Distribution of meteor streams in Right Ascension.

In North Polar Distance the showers are placed as follows:

| N.P.D. | Radiants. | Percentage. | N.P.D. | Radiants. | Percentage. |
|---|---|---|---|---|---|
| ° ° | | | ° ° | | |
| 0 to 9 | 39 | 1·3 | 60 to 69 | 392 | 12·9 |
| 10 „ 19 | 141 | 4·7 | 70 „ 79 | 335 | 11·0 |
| 20 „ 29 | 243 | 8·0 | 80 „ 89 | 211 | 6·9 |
| 30 „ 39 | 473 | 15·6 | 90 „ 99 | 127 | 4·2 |
| 40 „ 49 | 489 | 16·1 | + 99 | 170 | 5·6 |
| 50 „ 59 | 415 | 13·7 | | | |

The maximum obviously lies between 30° and 49° N.P.D., and the minimum naturally occurs at the pole, inasmuch as the zone 0° to 9° includes a much smaller area than any other.

The distribution of the observed radiants in N.P.D. is

affected by the differences in the areas of the several zones and their relative degrees of visibility. Though towards the pole the total space included in the zones becomes less, yet this is in a large measure compensated for by their more favourable position and the persistency with which they are displayed to view. The entire zones, from 0° to 49° N.P.D., never fall below the horizon, and such showers as they present are therefore determinable at any period of the year or time of night. This applies specially to English latitudes, but it also has a general reference (with perhaps slight modification in certain instances) because nearly all our existing observations of shooting stars have been made at stations having considerable (*i.e.* exceeding 35°) north latitude. The summary proves that while the two zones embraced between the parallels of 30° and 49° N.P.D. have the largest number of recorded streams, the three zones succeeding towards the equator exhibit a gradual decline, though each remains fairly prolific. The Andromedes, Perseids, and Quadrantids are arranged between 30° and 49°, while the Geminids, Leonids, and Lyrids, are clustered between 50° and 69° N.P.D. Considering all the circumstances, there do not appear to be great inequalities of grouping in North Polar Distance similar to those which undoubtedly occur in Right Ascension, but the point requires further investigation.

In considering the distribution of meteor streams, several important conditions must not be lost sight of. The bulk of the observations have been effected in the summer months, whence it necessarily follows that such constellations as are most favourably visible at this period must certainly appear to exhibit a predominance of showers. I gave a summary in the *Monthly Notices*, vol. xxxix. p. 411, showing the comparative monthly numbers of meteors registered in twelve catalogues, and I have now added several others, the aggregate including 82,156 meteors, with the following result:

| Month. | Meteors Catalogued. | Percentage. | Month. | Meteors Catalogued. | Percentage. |
|---|---|---|---|---|---|
| January | 2804 | 3·4 | July | 10670 | 12·1 |
| February | 1826 | 2·2 | August | 31516 | 38·1 |
| March | 1764 | 2·1 | September | 4304 | 5·1 |
| April | 5585 | 6·8 | October | 6840 | 8·3 |
| May | 2120 | 2·6 | November | 8319 | 11·3 |
| June | 2353 | 2·9 | December | 4055 | 4·9 |

These numbers are derived from the catalogues of Corder, Denning, Denza, Heis, Konkoly, Lucas, Sawyer, Schmidt, Tupman, Weiss, Zezioli, and the Italian Meteoric Association, 1869, 1870, and 1872, and some minor lists.

Now, more than one-half the total number of observations were obtained in July and August, and, in point of fact, are

nearly all embraced between the period from July 20 to August 15. The majority of the observations have been secured before midnight, and it is therefore certain that the region of 31° to 60° R.A., which is for the most part either below the horizon or low in the north-east at the special epoch when the largest number of meteors have been recorded, is not rendered rich solely by the abundance of observations. Indeed the months of September, October, and November appear to have furnished, relatively to the number of meteors catalogued, by far the greatest number of showers in this quarter of the sky. I

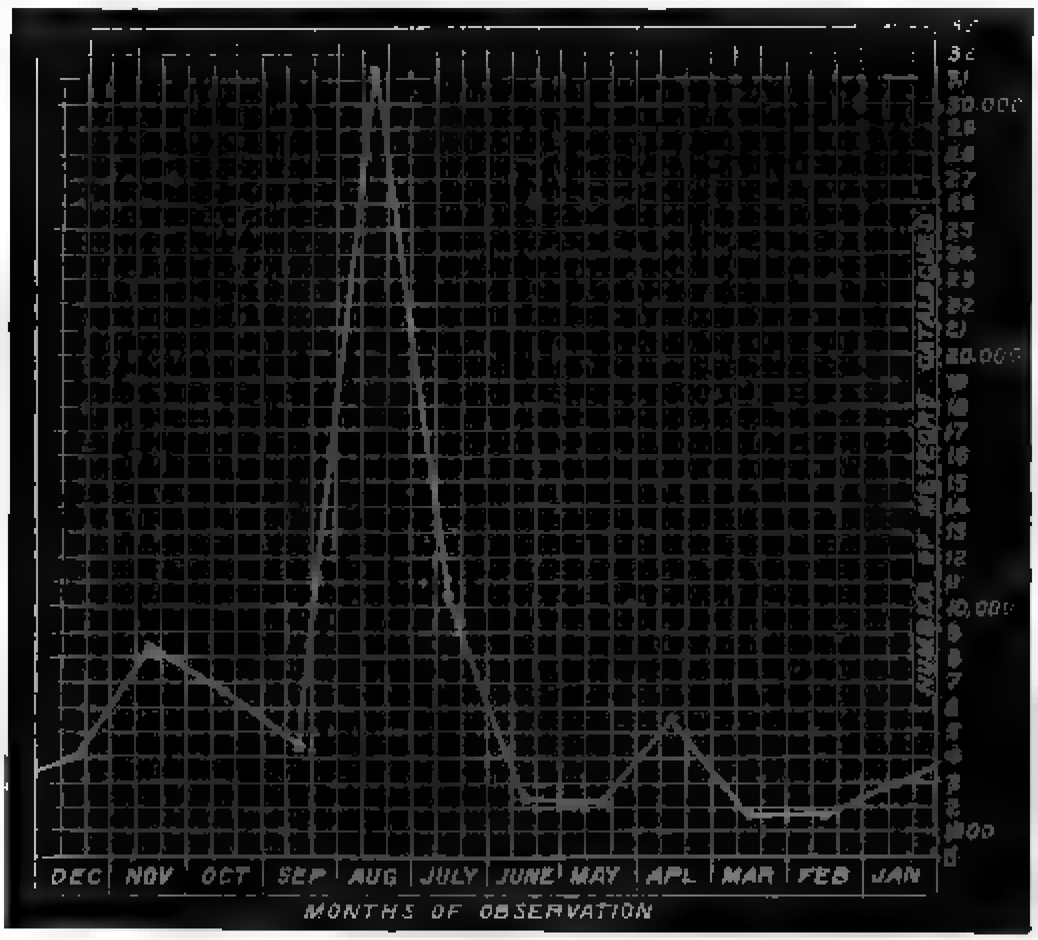


FIG. II.—Relative numbers of meteors catalogued during the twelve months.

believe, therefore, the great superabundance of streams about *Andromeda*, *Aries*, and *Perseus* is a real one.

We must remember that the large proportion of meteors catalogued in July, August, and later months is far from being entirely due to the more extensive watches undertaken at those times. It is attributable in a great measure to a real surplus in the visible number of meteors. All regular workers in this department agree as to the far greater frequency of meteors during the last half of the year as compared with the first half. From my own observations, up to the end of 1885, comprising 7,100 meteors, I find that the average horary number for one observer from January to June is 6·95, and from July to

December 12·65, so that the excess in favour of the last half of the year is nearly in the proportion of 2 to 1. From this we may conclude that both meteors and meteoric radiants display by far the greatest profusion between July and December, and that the densest region of radiation lies between 1° and 60° of R.A. This is indeed the most active part of the heavens even as late as November, when it is some 110° distant from the apex of the Earth's way.

The known meteor streams, considered in respect to their apparent distribution upon the celestial vault, exhibit special regions of density and scarcity, not exactly regulated by the direction of the Earth's motion. The maximum number of showers is rarely seen in that part of the firmament towards which the Earth is directed, though with a perfectly equal distribution of streams this would be expected. The richest showers usually come from positions far to the west of the Earth's apex, and this is sufficient evidence that they exhibit a special construction or grouping together. The Earth becomes alternately involved with rich and tenuous regions at intervals of about six months.

*Bristol*: 1886. *November* 9.

*Ephemeris for Physical Observations*

| Greenwich Noon. | | Angle of Position of ♃'s Axis. | Latitude of Earth above ♃'s Equator | Latitude of Sun above ♃'s Equator | Annual Parallax. | | Longitude of ♃'s Central Meridian. (878°·25) | Longitude of ♃'s Central Meridian. (870°·27) | Corr. for Phase. |
|---|---|---|---|---|---|---|---|---|---|
| | | P | B | *B* | A−L. | L−O. | I | II | |
| 1886 Dec. | 9 | 22°·064 | −2°·862 | −2°·796 | −7°·799 | 73°·435 | 34°·15 | 251°·43 | +0°·264 |
| | 14 | 21·877 | 2·893 | 2·804 | 8·282 | 74·297 | 104·86 | 282·24 | ·298 |
| | 19 | 21·694 | 2·923 | 2·813 | 8·726 | 75·119 | 175·62 | 313·10 | ·331 |
| | 24 | 21·516 | 2·952 | 2·821 | 9·127 | 75·898 | 246·45 | 344·02 | ·362 |
| | 29 | 21·345 | 2·980 | 2·829 | 9·481 | 76·630 | 317·34 | 15·00 | ·390 |
| 1887 Jan. | 3 | 21·182 | −3·008 | −2·836 | −9·784 | 77·311 | 28·29 | 46·05 | +0·415 |
| | 8 | 21·030 | 3·036 | 2·844 | 10·032 | 77·937 | 99·30 | 77·16 | ·437 |
| | 13 | 20·890 | 3·063 | 2·852 | 10·222 | 78·505 | 170·38 | 108·34 | ·444 |
| | 18 | 20·763 | 3·089 | 2·859 | 10·351 | 79·012 | 241·53 | 139·59 | ·465 |
| | 23 | 20·651 | 3·114 | 2·866 | 10·414 | 79·454 | 312·75 | 170·90 | ·471 |
| | 28 | 20·555 | 3·139 | 2·874 | 10·409 | 79·827 | 24·04 | 202·28 | ·470 |
| Feb. | 2 | 20·476 | 3·162 | −2·881 | −10·332 | 80·128 | 95·40 | 233·73 | +0·463 |
| | 7 | 20·416 | 3·185 | [illegible] | 10·181 | 80·356 | 166·83 | 265·26 | ·450 |
| | 12 | 20·376 | 3·206 | 2·894 | 9·954 | 80·508 | 238·32 | 296·85 | ·430 |
| | 17 | 20·355 | 3·225 | 2·901 | 9·649 | 80·582 | 309·88 | 328·51 | ·404 |
| | 22 | 20·355 | 3·242 | 2·908 | 9·265 | 80·577 | 21·51 | 0·23 | ·372 |
| | 27 | 20·375 | 3·258 | 2·914 | 8·802 | 80·492 | 93·20 | 32·02 | ·336 |
| Mar. | 4 | 20·416 | −3·271 | −2·920 | −8·261 | 80·329 | 164·95 | 63·86 | +0·296 |
| | 9 | 20·476 | 3·282 | 2·927 | 7·644 | 80·092 | 236·75 | 95·76 | ·254 |
| | 14 | 20·554 | 3·290 | 2·933 | 6·954 | 79·782 | 308·60 | 127·71 | ·210 |
| | 19 | 20·650 | 3·295 | 2·939 | 6·196 | 79·403 | 20·49 | 159·70 | ·167 |
| | 24 | 20·761 | 3·297 | 2·944 | 5·375 | 78·961 | 92·41 | 191·72 | ·126 |
| | 29 | 20·884 | 3·296 | 2·950 | 4·497 | 78·462 | 164·35 | 223·76 | ·088 |
| Apr. | [illegible] | 21·017 | −3·292 | −2·956 | −3·571 | 77·915 | 236·31 | 255·82 | +0·056 |
| | 8 | 21·158 | 3·285 | 2·961 | 2·607 | 77·330 | 308·28 | 287·88 | ·030 |
| | 13 | 21·303 | 3·274 | 2·966 | 1·614 | 76·716 | 20·23 | 319·93 | ·011 |
| | 18 | 21·451 | 3·260 | 2·971 | −0·602 | 76·084 | 92·16 | 351·97 | +0·002 |
| | 23 | 21·598 | 3·243 | 2·976 | +0·418 | 75·444 | 164·07 | 23·97 | −0·001 |
| | [illegible] | 21·741 | 3·223 | 2·981 | 1·434 | 74·808 | 235·93 | 55·93 | ·009 |
| May | 3 | 21·879 | −3·201 | −2·986 | +2·434 | 74·188 | 307·74 | 87·84 | −0·026 |
| | [illegible] | 22·009 | 3·177 | 2·991 | 3·408 | 73·594 | 19·48 | 119·68 | ·051 |
| | 13 | 22·129 | 3·151 | 2·995 | 4·347 | 73·035 | 91·15 | 151·46 | ·082 |
| | 18 | 22·238 | 3·124 | 3·000 | 5·242 | 72·520 | 162·74 | 183·16 | ·119 |
| | 23 | 22·335 | 3·096 | 3·004 | 6·085 | 72·058 | 234·25 | 214·77 | ·161 |

*of Jupiter* 1887. By A. Marth.

| Greenwich Noon | | Diameter Equat. | Polar. | Difference of limbs in A. R. | in Decl. | Defect of illumination. Equat. preceding limb | in A. R. | in Decl. north *l*. | *d* | *w* |
|---|---|---|---|---|---|---|---|---|---|---|
| 1886 | | ″ | ″ | s | ″ | ″ | s | ″ | ° | ° |
| Dec. | 9 | 32·32 | 30·26 | 2·168 | 30·56 | 0·15 | 0·009 | 0·02 | 7·79 | 269·69 |
| | 14 | 32·66 | 30·58 | 2·193 | 30·88 | ·17 | ·010 | ·02 | 8·27 | 269·57 |
| | 19 | 33·02 | 30·93 | 2·220 | 31·22 | ·19 | ·011 | ·03 | 8·71 | 269·46 |
| | 24 | 33·42 | 31·30 | 2·249 | 31·59 | ·21 | ·013 | ·03 | 9·11 | 269·37 |
| | 29 | 33·84 | 31·69 | 2·280 | 31·98 | ·23 | ·014 | ·03 | 9·47 | 269·28 |
| 1887 Jan. | 3 | 34·29 | 32·11 | 2·312 | 32·40 | 0·25 | 0·015 | 0·03 | 9·77 | 269·19 |
| | 8 | 34·76 | 32·55 | 2·346 | 32·84 | ·27 | ·016 | ·03 | 10·02 | 269·11 |
| | 13 | 35·26 | 33·01 | 2·381 | 33·31 | ·28 | ·017 | ·03 | 10·21 | 269·02 |
| | 18 | 35·77 | 33·50 | 2·417 | 33·79 | ·29 | ·018 | ·03 | 10·34 | 268·93 |
| | 23 | 36·31 | 34·01 | 2·455 | 34·30 | ·30 | ·018 | ·04 | 10·40 | 268·84 |
| | 28 | 36·87 | 34·53 | 2·494 | 34·82 | ·30 | ·018 | ·04 | 10·40 | 268·74 |
| Feb. | 2 | 37·44 | 35·06 | 2·533 | 35·36 | 0·30 | 0·018 | 0·03 | 10·32 | 268·63 |
| | 7 | 38·02 | 35·60 | 2·573 | 35·91 | ·30 | ·018 | ·03 | 10·17 | 268·51 |
| | 12 | 38·60 | 36·15 | 2·614 | 36·46 | ·29 | ·018 | ·03 | 9·94 | 268·37 |
| | 17 | 39·19 | 36·71 | 2·654 | 37·02 | ·28 | ·017 | ·03 | 9·64 | 268·23 |
| | 22 | 39·78 | 37·26 | 2·693 | 37·57 | ·26 | ·016 | ·03 | 9·26 | 268·06 |
| | 27 | 40·36 | 37·80 | 2·732 | 38·12 | ·24 | ·015 | ·02 | 8·80 | 267·86 |
| Mar. | 4 | 40·92 | 38·33 | 2·769 | 38·65 | 0·21 | 0·014 | 0·02 | 8·26 | 267·64 |
| | 9 | 41·46 | 38·83 | 2·804 | 39·16 | ·18 | ·012 | ·02 | 7·64 | 267·38 |
| | 14 | 41·97 | 39·30 | 2·837 | 39·64 | ·15 | ·010 | ·02 | 6·95 | 267·06 |
| | 19 | 42·44 | 39·74 | 2·867 | 40·09 | ·12 | ·008 | ·01 | 6·20 | 266·67 |
| | 24 | 42·86 | 40·14 | 2·894 | 40·49 | ·09 | ·006 | ·01 | 5·38 | 266·14 |
| | 29 | 43·23 | 40·49 | 2·917 | 40·84 | ·07 | ·004 | ·01 | 4·51 | 265·43 |
| Apr. | 3 | 43·54 | 40·78 | 2·935 | 41·14 | 0·04 | 0·003 | 0·00 | 3·60 | 264·35 |
| | 8 | 43·78 | 41·01 | 2·949 | 41·38 | ·02 | ·001 | — | 2·63 | 262·5 |
| | 13 | 43·96 | 41·17 | 2·959 | 41·55 | ·01 | ·001 | — | 1·64 | 258·7 |
| | 18 | 44·06 | 41·26 | 2·964 | 41·65 | on following | | on south | 0·68 | 242·8 |
| | 23 | 44·09 | 41·29 | 2·963 | 41·68 | limb | | limb | 0·52 | 123·4 |
| | 28 | 44·04 | 41·24 | 2·957 | 41·64 | 0·01 | 0·000 | 0·00 | 1·47 | 102·7 |
| May | 3 | 43·91 | 41·12 | 2·946 | 41·53 | ·02 | ·001 | ·00 | 2·44 | 95·3 |
| | 8 | 43·72 | 40·94 | 2·931 | 41·35 | ·04 | ·002 | ·01 | 3·41 | 93·24 |
| | 13 | 43·46 | 40·70 | 2·911 | 41·10 | ·06 | ·004 | ·01 | 4·34 | 92·07 |
| | 18 | 43·14 | 40·40 | 2·888 | 40·80 | ·09 | ·005 | ·02 | 5·24 | 91·30 |
| | 23 | 42·76 | 40·05 | 2·862 | 40·45 | ·12 | ·007 | ·02 | 6·08 | 90·76 |

| Greenwich Noon | Angle of Position of ♃'s Axis. | Latitude of Earth above ♃'s Equator. | Latitude of Sun above ♃'s Equator. | Annual Parallax. | | Longitude of ♃'s Central Meridian. (878°·25) | Longitude of ♃'s Central Meridian. (870°·27) | Corr. for Phase. |
|---|---|---|---|---|---|---|---|---|
| | P | B | *B* | A−L. | L−O. | I | II | |
| 1887 May 28 | 22°·418 | 3°·068 | 3°·008 | 6°·868 | 71°·655 | 305°·67 | 246°·29 | °·205 |
| June 2 | 22·487 | −3·040 | −3·012 | +7·586 | 71·317 | 17·00 | 277·72 | −0·250 |
| 7 | 32·542 | 3·013 | 3·016 | 8·236 | 71·047 | 88·24 | 309·06 | ·294 |
| 12 | 22·582 | 2·987 | 3·020 | 8·814 | 70·849 | 159·38 | 340·30 | ·337 |
| 17 | 22·608 | 2·961 | 3·023 | 9·318 | 70·726 | 230·42 | 11·45 | ·377 |
| 22 | 22·619 | 2·937 | 3·027 | 9·747 | 70·678 | 301·37 | 42·50 | ·412 |
| 27 | 22·615 | 2·915 | 3·030 | 10·101 | 70·705 | 12·24 | 73·47 | ·443 |
| July 2 | 22·567 | −2·895 | −3·033 | +10·380 | 70·806 | 83·02 | 104·35 | −0·467 |
| 7 | 22·564 | 2·876 | 3·036 | 10·586 | 70·981 | 153·71 | 135·15 | ·486 |
| 12 | 22·516 | 2·859 | 3·039 | 10·721 | 71·227 | 224·33 | 165·87 | ·498 |
| 17 | 22·454 | 2·845 | 3·042 | 10·787 | 71·542 | 294·88 | 196·52 | ·505 |
| 22 | 22·378 | 2·833 | 3·045 | 10·786 | 71·925 | 5·36 | 227·10 | ·505 |
| 27 | 22·288 | 2·823 | 3·047 | 10·720 | 72·372 | 75·77 | 257·62 | ·498 |
| Aug. 1 | 22·183 | −2·815 | −3·050 | +10·594 | 72·880 | 146·13 | 288·08 | −0·486 |
| 6 | 22·064 | 2·809 | 3·052 | 10·411 | 73·445 | 216·43 | 318·49 | ·470 |
| 11 | 21·931 | 2·804 | 3·054 | 10·173 | 74·065 | 286·69 | 348·85 | ·449 |
| 16 | 21·785 | 2·801 | 3·056 | 9·882 | 74·737 | 356·90 | 19·17 | ·424 |
| 21 | 21·624 | 2·800 | 3·058 | 9·543 | 75·458 | 67·08 | 49·45 | ·395 |
| 26 | 21·450 | 2·800 | 3·060 | 9·159 | 76·225 | 137·23 | 79·70 | ·364 |
| 31 | 21·261 | 2·801 | 3·061 | 8·732 | 77·034 | 207·35 | 109·92 | ·331 |
| Sept. 5 | 21·059 | −2·805 | −3·063 | +8·266 | 77·883 | 277·44 | 140·11 | −0·297 |

The angle A—L is the difference of the Jovicentric longitudes of the Sun and Earth, reckoned in the plane of *Jupiter's* equator L—O+180° the Jovicentric longitude of the Earth reckoned from O, the point of *Jupiter's* vernal equinox or the point of the ascending node of the planet's orbit on its equator. Two values of the "longitude of ♃'s central meridian" are given for each date, the first, computed with the daily rate of rotation 878°·25, being intended for comparing the observations of the white spots in the neighbourhood of the planet's equator; the second, computed with the rate 870°·27, for the observations of the remnant of the great reddish spot in the planet's southern hemisphere. The apparent irregularities in the motion of the white equatorial spots leave it doubtful whether the adopted slackened rate of rotation will be approximately correct during the approaching apparition of *Jupiter*. But observers who have instrumental and climatic opportunities for observing the spots assiduously can, after the first observations, easily make allowance for any changes of the positions of the spots in reference to the system I. of longitudes. If the slackening of the motion of the great

| Greenwich Noon | Diameter Equat. | Diameter Polar. | Difference of limbs in A. R. | Difference of limbs in Decl. | Defect of illumination. Equat. following limb | Defect of illumination. in A. R. following limb | Defect of illumination. in Decl. south *l*. | *d* | *w* |
|---|---|---|---|---|---|---|---|---|---|
| 1887 | " | " | s | " | " | s | " | ° | ° |
| May 28 | 42·33 | 39·65 | 2·832 | 40·05 | 0·15 | 0·009 | 0·02 | 6·86 | 90·34 |
| June 2 | 41·87 | 39·21 | 2·800 | 39·61 | 0·18 | 0·011 | 0·03 | 7·57 | 90·02 |
| 7 | 41·37 | 38·74 | 2·766 | 39·14 | ·21 | ·012 | ·03 | 8·22 | 89·75 |
| 12 | 40·84 | 38·25 | 2·731 | 38·64 | ·24 | ·014 | ·04 | 8·80 | 89·52 |
| 17 | 40·30 | 37·74 | 2·694 | 38·13 | ·27 | ·016 | ·04 | 9·30 | 89·33 |
| 22 | 39·74 | 37·22 | 2·657 | 37·60 | ·29 | ·017 | ·04 | 9·73 | 89·17 |
| 27 | 39·18 | 36·69 | 2·619 | 37·07 | ·30 | ·018 | ·04 | 10·09 | 89·02 |
| July 2 | 38·61 | 36·16 | 2·582 | 36·53 | 0·31 | 0·018 | 0·04 | 10·37 | 88·89 |
| 7 | 38·05 | 35·63 | 2·545 | 36·00 | ·32 | ·019 | ·05 | 10·57 | 88·78 |
| 12 | 37·49 | 35·11 | 2·509 | 35·47 | ·33 | ·019 | ·05 | 10·71 | 88·68 |
| 17 | 36·95 | 34·60 | 2·473 | 34·95 | ·33 | ·019 | ·04 | 10·77 | 88·59 |
| 22 | 36·42 | 34·10 | 2·439 | 34·45 | ·32 | ·019 | ·04 | 10·77 | 88·50 |
| 27 | 35·91 | 33·62 | 2·406 | 33·96 | ·31 | ·019 | ·04 | 10·71 | 88·43 |
| Aug. 1 | 35·41 | 33·16 | 2·374 | 33·49 | 0·30 | 0·018 | 0·04 | 10·58 | 88·36 |
| 6 | 34·94 | 32·72 | 2·344 | 33·04 | ·29 | ·017 | ·04 | 10·40 | 88·29 |
| 11 | 34·48 | 32·29 | 2·316 | 32·61 | ·27 | ·016 | ·03 | 10·16 | 88·22 |
| 16 | 34·05 | 31·89 | 2·289 | 32·20 | ·25 | ·015 | ·03 | 9·87 | 88·15 |
| 21 | 33·65 | 31·51 | 2·264 | 31·81 | ·23 | ·014 | ·03 | 9·53 | 88·08 |
| 26 | 33·26 | 31·15 | 2·241 | 31·44 | ·21 | ·013 | ·03 | 9·15 | 88·01 |
| 31 | 32·91 | 30·81 | 2·219 | 31·10 | ·19 | ·012 | ·02 | 9·72 | 87·94 |
| Sept. 5 | 32·57 | 30·50 | 2·199 | 30·78 | 0·17 | 0·010 | 0·02 | 9·26 | 87·87 |

reddish spot should be maintained, its place will be found near the zero meridian of the system II. of longitudes. The periods of rotation corresponding to the adopted rates are

| | | | h | m | s |
|---|---|---|---|---|---|
| I. daily rate | 878°·25 | period | 9 | 50 | 15·88 |
| II. | 870°·27 | | 9 | 55 | 40·63 |

The differences of successive values in the two columns for "Longitude, &c.," amount for the intervals of five days to 12 rotations in addition to the differences directly deduced, so that, for instance, the differences of the values for Dec. 14 and Dec. 9 are 4390°·71 and 4350°·81. The addition of the correction for phase "to the longitude of ♃'s central meridian" gives the longitude of the meridian which bisects the illuminated disc. A list of Greenwich times when their longitude is 0° will be found further on.

The diameters of the disc, etc., depend on the same assumed values as in the ephemeris for the preceding apparition. The formulæ employed may be found in vol. xlv. p. 508.

The inclinations $\gamma$ and the ascending nodes $\Gamma$ of the orbits of the four satellites of *Jupiter* in reference to the plane of the planet's equator are the following, the longitudes of the nodes being reckoned from O, the point of the ascending node of *Jupiter's* orbit on the equator:

| | | Sat. I. | | Sat. II. | | Sat. III. | | Sat. IV. | |
|---|---|---|---|---|---|---|---|---|---|
| 1886. | | $\gamma_1$ | $\Gamma_1$ | $\gamma_2$ | $\Gamma_2$ | $\gamma_3$ | $\Gamma_3$ | $\gamma_4$ | $\Gamma_4$ |
| Nov. | 9 | 0°·0118 | 295°·6 | 0°·4923 | 294°·06 | 0°·1476 | 250°·93 | 0°·3206 | 330°·40 |
| 1887. Jan. | 8 | ·0117 | 294·3 | ·4925 | 292·17 | ·1466 | 250·67 | ·3206 | 330·51 |
| Mar. | 9 | ·0117 | 292·9 | ·4927 | 290·28 | ·1455 | 250·40 | ·3205 | 330·62 |
| May | 8 | ·0116 | 291·5 | ·4928 | 288·39 | ·1444 | 250·11 | ·3203 | 330·74 |
| July | 7 | ·0116 | 290·1 | ·4928 | 286·50 | ·1433 | 249·81 | ·3200 | 330·86 |
| Sept. | 5 | ·0115 | 288·6 | ·4928 | 284·60 | ·1422 | 249·49 | ·3196 | 330·98 |
| Nov. | 4 | 0·0114 | 287·0 | 0·4928 | 282·69 | 0·1411 | 249·15 | 0·3191 | 331·09 |

Has the eclipse of Sat. IV. on May 17, 1886, which was not given by the Tables, but the probable occurrence of which was mentioned in vol. xlv. p. 509, not been observed anywhere?

The following is a list of Greenwich mean times, when the zero meridian in the assumed two systems of longitudes will pass the middle of the illuminated disc. To save printing, the time of only one passage is given for each day, and the others must be found by interpolation, or, if greater accuracy is not required, by adding or subtracting $9^h\ 50^m$ in the first system, and $9^h\ 56^m$ in the second.

| | | I (878°·25) | II (870°·27) | | | I (878°·25) | II (870°·27) |
|---|---|---|---|---|---|---|---|
| 1886 | | h m | h m | 1886 | | h m | h m |
| Dec. | 9 | 18 44·2 | 12 55·0 | Dec. | 25 | 18 26·8 | 16 8·8 |
| | 10 | 14 24·9 | 18 42·2 | | 26 | 14 7·5 | 12 0·2 |
| | 11 | 19 55·9 | 14 33·7 | | 27 | 19 38·4 | 17 47·4 |
| | 12 | 15 36·6 | 20 21·0 | | 28 | 15 19·0 | 13 38·8 |
| | 13 | 21 7·6 | 16 12·5 | | 29 | 20 49·9 | 19 26·0 |
| | 14 | 16 48·2 | 12 3·9 | | 30 | 16 30·5 | 15 17·4 |
| | 15 | 12 28·9 | 17 51·2 | | 31 | 12 11·1 | 21 4·5 |
| | 16 | 17 59·8 | 13 42·6 | 1887 | | | |
| | 17 | 13 40·5 | 19 29·9 | Jan. | 1 | 17 42·0 | 16 56·0 |
| | 18 | 19 11·5 | 15 21·3 | | 2 | 13 22·6 | 12 47·4 |
| | 19 | 14 52·1 | 21 8·5 | | 3 | 18 53·5 | 18 34·5 |
| | 20 | 20 23·1 | 17 0·0 | | 4 | 14 34·1 | 14 26·0 |
| | 21 | 16 3·7 | 12 51·5 | | 5 | 20 5·0 | 20 13·1 |
| | 22 | 21 34·7 | 18 38·7 | | 6 | 15 45·6 | 16 4·5 |
| | 23 | 17 15·3 | 14 30·1 | | 7 | 11 26·2 | 11 55·9 |
| | 24 | 12 55·9 | 20 17·3 | | 8 | 16 57·0 | 17 43·0 |

| 1887 | I (878°·25) h m | II (870°·27) h m | 1887 | I (878°·25) h m | II (870°·27) h m |
|---|---|---|---|---|---|
| Jan. 9 | 12 37·6 | 13 34·4 | Feb. 13 | 18 39·7 | 17 26·3 |
| 10 | 18 8·5 | 19 21·5 | 14 | 14 20·2 | 13 17·6 |
| 11 | 13 49·0 | 15 12·9 | 15 | 10 0·6 | 19 4·5 |
| 12 | 19 19·9 | 11 4·3 | 16 | 15 31·3 | 14 55·8 |
| 13 | 15 0·4 | 16 51·4 | 17 | 11 11·7 | 10 47·1 |
| 14 | 10 41·0 | 12 42·8 | 18 | 16 42·4 | 16 34·0 |
| 15 | 16 11·8 | 18 29·8 | 19 | 12 22·8 | 12 25·4 |
| 16 | $10^h\cdot5$ conj. of ♃ with | | 20 | 17 53·5 | 18 12·1 |
| | * $8^m$ W.B. 14, 111 | | 21 | 13 33·9 | 14 3·4 |
| | * 0'·2 north of limb. | | 22 | 19 4·6 | 19 50·3 |
| — | 11 52·4 | 14 21·2 | 23 | 14 45·0 | 15 41·5 |
| 17 | 17 23·2 | 10 12·6 | 24 | 10 25·4 | 11 32·7 |
| 18 | 13 3·7 | 15 59·6 | 25 | 15 56·0 | 17 19·6 |
| 19 | 18 34·6 | 11 51·0 | 26 | 11 36·5 | 13 10·8 |
| 20 | 14 15·1 | 17 38·0 | 27 | 17 7·1 | 18 57·7 |
| 21 | 19 45·9 | 13 29·4 | 28 | 12 47·5 | 14 48·9 |
| 22 | 15 26·4 | 19 16·4 | March 1 | 18 18·1 | 10 40·2 |
| 23 | 11 7·0 | 15 7·8 | 2 | 13 58·5 | 16 27·0 |
| 24 | 16 37·7 | 10 59·1 | 3 | 9 38·9 | 12 18·2 |
| 25 | 12 18·3 | 16 46·2 | 4 | 15 9·5 | 18 5·1 |
| 26 | 17 49·0 | 12 37·5 | 5 | 10 49·9 | 13 56·3 |
| 27 | 13 29·6 | 18 24·5 | 6 | 16 20·5 | 9 47·5 |
| 28 | 19 0·3 | 14 15·9 | 7 | 12 0·9 | 15 34·3 |
| 29 | 14 40·8 | 20 2·9 | 8 | 17 31·5 | 11 25·5 |
| 30 | 20 11·6 | 15 54·2 | 9 | 13 11·8 | 17 12·3 |
| 31 | 15 52·1 | 11 45·5 | 10 | 8 52·2 | 13 3·6 |
| Feb. 1 | 11 32·6 | 17 32·5 | 11 | 14 22·8 | 8 54·8 |
| 2 | 17 3·3 | 13 23·8 | 12 | 10 3·2 | 14 41·6 |
| 3 | 12 43·8 | 19 10·8 | 13 | 15 33·7 | 10 32·8 |
| 4 | 18 14·5 | 15 2·1 | 14 | 11 14·1 | 16 19·6 |
| 5 | 13 55·0 | 10 53·4 | 15 | 16 44·7 | 12 10·8 |
| 6 | 19 25·8 | 16 40·4 | 16 | 12 25·0 | 8 1·9 |
| 7 | 15 6·2 | 12 31·7 | 17 | 8 5·4 | 13 48·7 |
| 8 | 10 46·7 | 18 18·6 | 18 | 13 36·0 | 9 39·9 |
| 9 | 16 17·4 | 14 9·9 | 19 | 9 16·3 | 15 26·7 |
| 10 | 11 57·9 | 10 1·2 | 20 | 14 46·9 | 11 17·9 |
| 11 | 17 28·6 | 15 48·1 | 21 | 10 27·2 | 17 4·7 |
| 12 | 13 9·0 | 11 39·4 | 22 | 15 57·8 | 12 55·8 |

| 1887 | I (878°·25) h m | II (870°·27) h m | 1887 | I (878°·25) h m | II (870°·27) h m |
|---|---|---|---|---|---|
| March 23 | 11 38·1 | 8 47·0 | April 30 | 14 24·6 | 10 1·1 |
| 24 | 17 8·7 | 14 33·8 | May 1 | 10 4·9 | 5 52·3 |
| 25 | 12 49·0 | 10 25·0 | 2 | 5 45·3 | 11 39·1 |
| 26 | 8 29·4 | 16 11·7 | 3 | 11 15·9 | 7 30·3 |
| 27 | 13 59·9 | 12 2·9 | 4 | 6 56·3 | 13 17·2 |
| 28 | 9 40·2 | 7 54·1 | 5 | 12 26·9 | 9 8·4 |
| 29 | 15 10·8 | 13 40·8 | 6 | 8 7·3 | 14 55·2 |
| 30 | 10 51·1 | 9 32·0 | 7 | 13 37·9 | 10 46·5 |
| 31 | 16 21·6 | 15 18·8 | 8 | 9 18·3 | 6 37·7 |
| April 1 | 12 2·0 | 11 9·9 | 9 | 14 49·0 | 12 24·5 |
| 2 | 7 42·3 | 7 1·1 | 10 | 10 29·4 | 8 15·8 |
| 3 | 13 12·8 | 12 47·9 | 11 | 6 9·8 | 14 2·7 |
| 4 | 8 53·2 | 8 39·0 | 12 | 11 40·5 | 9 53·9 |
| 5 | 14 23·7 | 14 25·8 | 13 | 7 20·9 | 5 45·2 |
| 6 | 10 4·0 | 10 16·9 | 14 | 12 51·6 | 11 32·1 |
| 7 | 15 34·6 | 6 8·1 | 15 | 8 32·0 | 7 23·3 |
| 8 | 11 14·9 | 11 54·8 | 16 | 14 2·7 | 13 10·2 |
| 9 | 6 55·3 | 7 46·0 | 17 | 9 43·1 | 9 1·5 |
| 10 | 12 25·8 | 13 32·8 | 18 | 5 23·6 | 14 48·4 |
| 11 | 8 6·1 | 9 23·9 | 19 | 10 54·3 | 10 39·7 |
| 12 | 13 36·6 | 15 10·7 | 20 | 6 34·8 | 6 31·0 |
| 13 | 9 17·0 | 11 1·9 | 21 | 12 5·5 | 12 18·0 |
| 14 | 14 47·5 | 6 53·0 | 22 | 7 46·0 | 8 9·3 |
| 15 | 10 27·9 | 12 39·8 | 23 | 13 16·7 | 13 56·2 |
| 16 | 6 8·2 | 8 30·9 | 24 | 8 57·2 | 9 47·5 |
| 17 | 11 38·7 | 14 17·7 | 25 | 14 27·9 | 5 38·8 |
| 18 | 7 19·1 | 10 8·9 | 26 | 10 8·4 | 11 25·8 |
| 19 | 12 49·6 | 6 0·0 | 27 | 5 48·9 | 7 17·2 |
| 20 | 8 30·0 | 11 46·8 | 28 | 11 19·7 | 13 4·2 |
| 21 | 14 0·5 | 7 38·0 | 29 | 7 0·2 | 8 5[illegible]·5 |
| 22 | 9 40·8 | 13 24·7 | 30 | 12 30·9 | 14 42·5 |
| 23 | 15 11·4 | 9 15·9 | 31 | 8 11·5 | 10 33·8 |
| 24 | 10 51·7 | 15 2·7 | June 1 | 13 42·3 | 6 25·2 |
| 25 | 6 32·1 | 10 53·9 | 2 | 9 22·8 | 12 12·2 |
| 26 | 12 2·7 | 6 45·1 | 3 | 5 3·3 | 8 3·6 |
| 27 | 7 43·0 | 12 31·9 | 4 | 10 34·1 | 13 50·7 |
| 28 | 13 13·6 | 8 23·1 | 5 | 6 14·7 | 9 42·0 |
| 29 | 8 54·0 | 14 9·9 | 6 | 11 45·5 | 5 33·4 |

| 1887 | I (878°·25) h m | II (870°·27) h m | 1887 | I (878°·25) h m | II (870°·27) h m |
|---|---|---|---|---|---|
| June 7 | 7 26·1 | 11 20·5 | July 15 | 10 26·2 | 12 48·3 |
| 8 | 12 56·9 | 7 11·9 | 16 | 6 6·9 | 8 39·8 |
| 9 | 8 37·5 | 12 59·0 | 17 | 11 38·0 | 4 31·4 |
| 10 | 14 8·4 | 8 50·3 | 18 | 7 18·7 | 10 18·7 |
| 11 | 9 48·9 | 14 37·4 | 19 | 12 49·8 | 6 10·3 |
| 12 | 5 29·5 | 10 28·9 | 20 | 8 30·6 | 11 57·6 |
| 13 | 11 0·4 | 6 20·3 | 21 | 4 11·3 | 7 49·2 |
| 14 | 6 41·0 | 12 7·4 | 22 | 9 42·4 | 13 36·6 |
| 15 | 12 11·9 | 7 58·8 | 23 | 5 23·2 | 9 28·1 |
| 16 | 7 52·5 | 13 46·0 | 24 | 10 54·3 | 5 19·7 |
| 17 | 13 23·4 | 9 37·4 | 25 | 6 35·0 | 11 7·1 |
| 18 | 9 4·0 | 5 28·8 | 26 | 12 6·2 | 6 58·7 |
| 19 | 14 34·9 | 11 16·0 | 27 | 7 46·9 | 12 46·0 |
| 20 | 10 15·6 | 7 7·4 | 28 | 13 18·1 | 8 37·6 |
| 21 | 5 56·2 | 12 54·6 | 29 | 8 58·8 | 4 29·2 |
| 22 | 11 27·1 | 8 46·1 | 30 | 4 39·6 | 10 16·6 |
| 23 | 7 7·8 | 14 33·3 | 31 | 10 10·8 | 6 8·2 |
| 24 | 12 38·7 | 10 24·7 | Aug. 1 | 5 51·5 | 11 55·6 |
| 25 | 8 19·4 | 6 16·2 | 2 | 11 22·7 | 7 47·2 |
| 26 | 13 50·3 | 12 3·4 | 3 | 7 3·5 | 3 38·8 |
| 27 | 9 31·0 | 7 54·9 | 4 | 12 34·7 | 9 26·2 |
| 28 | 5 11·6 | 13 42·1 | 5 | 8 15·4 | 5 17·9 |
| 29 | 10 42·6 | 9 33·6 | 6 | 3 56·2 | 11 5·3 |
| 30 | 6 23·3 | 5 25·1 | 7 | 9 27·4 | 6 56·9 |
| July 1 | 11 54·3 | 11 12·3 | 8 | 5 8·2 | 12 44·3 |
| 2 | 7 35·0 | 7 3·8 | 9 | 10 39·4 | 8 35·9 |
| 3 | 13 6·0 | 12 51·1 | 10 | 6 20·2 | 4 27·6 |
| 4 | 8 46·7 | 8 42·6 | 11 | 11 51·4 | 10 15·0 |
| 5 | 14 17·7 | 14 29·9 | 12 | 7 32·2 | 6 6·4 |
| 6 | 9 58·4 | 10 21·4 | 13 | 13 3·4 | 11 54·1 |
| 7 | 5 39·1 | 6 12·9 | 14 | 8 44·2 | 7 45·7 |
| 8 | 11 10·1 | 12 0·2 | 15 | 4 25·0 | 3 37·3 |
| 9 | 6 50·8 | 7 51·7 | 16 | 9 56·2 | 9 24·3 |
| 10 | 12 21·9 | 13 39·0 | 17 | 5 37·0 | 5 16·4 |
| 11 | 8 2·6 | 9 30·5 | 18 | 11 8·2 | 11 3·9 |
| 12 | 13 33·6 | 5 22·1 | 19 | 6 49·0 | 6 55·5 |
| 13 | 9 14·4 | 11 9·4 | 20 | 12 20·2 | 12 43·0 |
| 14 | 4 55·1 | 7 0·9 | 21 | 8 1·0 | 8 34·6 |

| 1887 | I (878°·25) | II (870°·27) | 1887 | I (878°·25). | II (870°·27) |
|---|---|---|---|---|---|
| | h m | h m | | h m | h m |
| Aug. 22 | 3 41·9 | 4 26·3 | Aug. 29 | 12 49·3 | 5 15·3 |
| 23 | 9 13·1 | 10 13·7 | 30 | 8 30·1 | 11 2·8 |
| 24 | 4 53·9 | 6 5·4 | 31 | 4 10·9 | 6 54·4 |
| 25 | 10 25·1 | 11 52·9 | Sept. 1 | 9 42·1 | 12 41·9 |
| 26 | 6 6·0 | 7 44·5 | 2 | 5 23·0 | 8 33·6 |
| 27 | 11 37·2 | 3 36·2 | 3 | 10 54·2 | 4 25·3 |
| 28 | 7 18·0 | 9 23·7 | 4 | 6 35·1 | 10 12·7 |

// MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

Vol. XLVII. December 10, 1886. No. 2

J. W. L. Glaisher, M.A., F.R.S., President, in the Chair.

Captain Robert Dowling, Denmark House, Queen's Terrace, Southampton;
Rev. Robert Sparke Hutchings, Alderbury Vicarage, Salisbury;
Rev. Harry Pool Slade, Tow Law, Darlington; and
Washington Teasdale, Rosehurst, Headingley, Leeds;

were balloted for and duly elected Fellows of the Society.

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*On Hartwig's Nova Andromedæ.* By Ralph Copeland, Ph.D.

On September 1, 1885, a telegram arrived at Dun Echt Observatory, which had been sent from Kiel by Prof. Krueger at 12 o'clock on the previous night. It ran: "Variation in *Andromeda* nebula found by Dr. Hartwig, starlike nucleus; please look for it." Dun Echt Circular, No. 97, to this effect was forthwith circulated, and preparations were made for examining the nebula.

The night was not very favourable, but with the 6-inch Simms' telescope and a power of only 28, it was seen that the centre of the great nebula was occupied by an object "exactly like a star; yellowish in colour." It was estimated of the $7\frac{1}{2}$ magnitude, but respecting this and other estimations with a very low power see the remarks further on. Viewed through a prism, held between the eye and the eyepiece, the first glance

showed that the spectrum had little or nothing in common with the brilliant spectrum of Schmidt's *Nova Cygni* in its earlier stages. The spectrum was continuous from end to end, and only on close examination could slight condensations indicative of bright lines be detected. The spectrum was not considered to differ strikingly from that of the nebula.

September 2 was cloudy, but a clear interval shortly after midnight on the 3rd enabled Lord Crawford and the writer to examine the *Nova* critically with the 15-inch Equatorial; it was then seen that following the new star, a little to the north, was a nebulous object. Naturally concluding that this might be the nucleus of the Great Nebula, the relative position of the objects was measured with the micrometer, and they were also connected with an 11½ magnitude star some 9½ seconds preceding. On comparing the interval between this latter star and the nebula with a rough measure taken at Birr Castle on October 25, 1851, it was possible to announce on September 5, in Circular 98, "that the *Nova* is most probably situated some $1^s{\cdot}6$ preceding, and 5″ south of the old nucleus, which is much overpowered by the light of the star." To test this conclusion the measurements were repeated from time to time as occasion offered, the place of *Nova* being at the same time determined with the Transit Circle. The following is a summary of the results for each night:—

*Micrometrical Observations with the 15-inch Equatorial.*

| Date. 1885. | | Measured. Position-Angle. | Measured. Distance. | Derived. Δα | Derived. Δδ | No. of Measures. | Observer. |
|---|---|---|---|---|---|---|---|
| | | ° ′ | ″ | s | ″ | | |
| **1. Nebular Nucleus to $11\frac{1}{2}^m$ star preceding.** | | | | | | | |
| Sept. 5 | | ... ... | 124·65 | ... | ... | 2 | R. C. |
| 17 | | 261 3 | 124·98 | −10·846 | −19·44 | 6 | „ |
| 1885·71 | Mean | 261 3 ± 5′·3 | 124·90 ± 0″·29 | −10·839 ± 0s·025 | −19·43 ± 0″·20 | | |
| **2. *Nova* to $11\frac{1}{2}^m$ star preceding.** | | | | | | | |
| Sept. 3 | | 261 41 | 109·97 | −9·559 | −15·91 | 2 | „ |
| 9 | | 262 7 | 109·73 | −9·549 | −15·05 | 4 | „ |
| 17 | | 262 14 | 110·26 | −9·598 | −14·90 | 6 | „ |
| 1885·70 | Mean | 262 7 ± 12′·6 | 110·04 ± 0″·24 | −9·575 ± 0s·021 | −15″·12 ± 0″·40 | 12 | |
| **3. *Nova* to nebula nucleus.** | | | | | | | |
| Sept. 3 | | 73 16 | 18·81 | +1·582 | + 5·42 | 1 | „ |
| 9 | | 73 20 | 16·11 | +1·356 | + 4·62 | 2 | L. B. |
| 12 | | 75 5 | 16·18 | +1·374 | + 4·16 | 2 | R. C. |
| 19 | | 73 53 | 16·62 | +1·403 | + 4·61 | 6 | „ |
| Dec. 2 | | 74 41 | 16·65 | +1·411 | + 4·40 | 8 | „ |
| 1885·79 | Mean | 74 15 ± 21′·6 | 16·65 ± 0″·26 | +1·408 ± 0s·022 | + 4·52 + 0″·12 | 19 | |
| **4. *Nova* to $13^m$ star.** | | | | | | | |
| Oct. 2 | | 172 9 | 157·05 | +1·884 | −155·28 | 2 | „ |
| **5. *Nova* to $11^m$ star.** | | | | | | | |
| Oct. 2 | | 156 53 | 231·01 | +7·977 | −212·46 | 2 | „ |

*Meridian Observations of Nova Andromedæ with the 8-inch Transit Circle.*

| 1885. | Apparent α h m s | Red. s | Apparent δ. ° ′ ″ | Red. ″ | Observer. |
|---|---|---|---|---|---|
| Sept. 3 | 0 36 30·86 | −4·11 | +40 38 24·8 | −10·4 | L. B. |
| 10 | 30·85 | −4·23 | ... | ... | " |
| 15 | 31·10 | −4·30 | 28·6 | −14·8 | " |
| 19 | 31·06 | −4·35 | 29·4 | −15·9 | " |
| 25 | 31·11 | −4·42 | 30·5 | −17·7 | " |

*Mean Equinox* 1885·0.

| 1885. | α h m s | δ ° ′ ″ |
|---|---|---|
| Sept. 3 | 0 36 26·75 | +40 38 14·4 |
| 10 | 26·62 | ... |
| 15 | 26·80 | 13·8 |
| 19 | 26·71 | 13·5 |
| 25 | 26·69 | 12·8 |

on the mean of which is based the following table:—

*Mean Places* 1885·0. (*Berliner Jahrbuch.*)

| | α h m s | δ ° ′ ″ |
|---|---|---|
| 11½ mag. star | 0 36 17·14 | +40 37 58·5 |
| Nova Andr. | 0 36 26·71 | +40 38 13·6 |
| Neb. nucleus | 0 36 28·08 | +40 38 18·1 |
| 13 mag. star | 0 36 28·59 | +40 35 38·0 |
| 11 mag. star | 0 36 34·69 | +40 34 41·1 |

Observers: L. B. = Dr. Ludwig Becker; R. C. = Ralph Copeland.

The mean errors of the micrometrical measures are derived from a comparison of the original readings.

The relative position of the nucleus of the Great Nebula and the 11½-magnitude star preceding is shown directly in 1; but it also results from the sum of 2 and 3, which give

| | Δα | Δδ |
|---|---|---|
| 11½ᵐ star to nebula | $-10^s{\cdot}983 \pm 0^s{\cdot}030$ | $-19''{\cdot}64 \pm 0''{\cdot}42$ |

which combined with 1 affords the mean value

| | Δα | Δδ |
|---|---|---|
| 11½ᵐ star to nebula | $-10^s{\cdot}898 \pm 0^s{\cdot}019$ | $-19''{\cdot}47 \pm 0''{\cdot}18$ |

These quantities having been more frequently measured at various observatories than any other feature connected with the

nebula, the earlier observations are here collected and brought up to 1885·0.

| | Pos. | Precession. | Distance. | 1885·0. Δα | Δδ |
|---|---|---|---|---|---|
| | ° ′ | ′ | ″ | s | ″ |
| Lamont,* 1836, Oct. 13 and 14 .. .. ... | 81 12·2 | +3·3 | 125·24 | −10·883 | −19·05 |
| O. Struve,† 1847 to 1864, 10 nights, 1850·97 ... | 81 26 | +2·4 | 125·13 | −10·871 | −18·55 |
| Lord Rosse,‡ 1851, Oct. 25 ... ... | 83 | +2·3 | | −10·639 | −14·79 |
| D'Arrest,§ 1863, Aug. 12 $\Delta\alpha = -11^s{\cdot}26$ | | | | −11·28 | |
| 1865, July 30 $\Delta\alpha = -11^s{\cdot}60$ | | | | −11·62 | |
| H. Vogel,‖ 1866, Oct. 19 $\Delta\alpha = -10^s{\cdot}79$, $\Delta\delta = -19''{\cdot}4$ | | +1·3 | | −10·807 | −19·35 |

Of these results those by Lord Rosse and D'Arrest, from the nature of the apparatus employed, are much less accurate than the others. The remaining observations, although somewhat discordant, show a great relative fixity in the two objects, the $\Delta\delta$ alone indicating a slight possibility of progressive change.

*The Spectrum.*

As will be seen further on, the New Star was of about the 8½ magnitude when first observed at Dun Echt on Sept. 1, 1885. It was therefore *a priori* fairly within range of the spectroscope; the weather, however, only permitted a brief examination, chiefly by looking through a prism into the eyepiece, with the results already mentioned, that the spectrum was continuous, with feeble traces of bright lines, and much resembled that of the Great Nebula. The star was "yellowish" in colour on this night, and "full yellow" on Sept. 3. It was not until the 10th that a settled fine night permitted a close spectroscopic examination. With the unmagnified dispersion of a direct-vision Vogel spectroscope the spectrum extended from W.L. $670^{mmm}$ to $453^{mmm}$, or from between B and C to half-way between F and G. When the spectrum was sufficiently narrow all the colours were visible, with a suspicion of brighter points in the line. An attempt was made to measure these with the Grubb spectroscope and a flint prism of only 40° refracting angle. This instrumental change cut down the spectrum to the limits of $600^{mmm}$ and $456^{mmm}$, with a maximum at $544{\cdot}4^{mmm}$ and "a suspicion of a bright line, but hardly more," at $482{\cdot}2^{mmm}$. With the same apparatus the spectrum appeared *quite continuous* on Sept. 11, but again showed traces of bands on the 13th, and was slightly banded on the 15th. Traces of a condensation of light were seen at W.L. $471{\cdot}6^{mmm}$ on Sept. 20.

* *Annalen der K. Sternwarte, München*, vol. xxxii. (1869), p. 306.
† *Mélanges Mathématiques et Astronomiques*, vol. iii. p. 571.
‡ *Phil. Trans.*, 1861, p. 709. § *Siderum Nebulosorum Obs.*
‖ *Beobachtungen von Nebelflecken*, &c., Leipzig, 1867, p. 65.

By the end of September a special acute prism of only 15° angle was received from Mr. Hilger. This had been made with a view to obtaining a very short and relatively bright spectrum, in which it might be possible to measure the positions of the brighter bands. But by this time *Nova* had fallen to about 9·8 magnitude, so that, in spite of the very low dispersion, only traces of two brighter points towards the yellow end of the spectrum could be made out on September 30, the rest of the spectrum appearing absolutely continuous. On October 1, by taking every precaution in the way of moderating the illumination, and protecting the eyes from all extraneous light with a black cloth, these two lines and a still fainter one were measured with a power of 7 on the viewing telescope. The measures and wave-lengths are:—

| | Screw. r | p | W.L. mmm. | Means. mmm. |
|---|---|---|---|---|
| Band 1 | 52 | 25·7 | 557·1 | 546·8 |
| | | 4·9 | 541·8 | |
| | | 4·6 | 541·5 | |
| Band 2 | 51 | 54·3 | 510·1 | 514·0 |
| | | 69·4 | 519·5 | |
| | | 58·1 | 512·4 | |
| Band 3 | 51 | 23·1 | 493·1 | 489·2 |
| | | 16·9 | 489·9 | |
| | | 5·8 | 484·5 | |
| Red end | 52 | 48·7 | 575·8 | 575·8 |
| Violet end | 50 | 67·2 | 467·6 | 467·6 |

Respecting the discordancy of these measures it must be noted that, since one revolution of the tangent-screw covers 10′ of arc, the whole visible spectrum was but slightly more than 18′ in length; the measures for the three bands, therefore, range over 2′·1, 1′·5, and 1′·7 respectively, arcs which cannot be considered excessive for so low a power as 7 diameters, on such ill-defined objects. Indeed, the task of measuring these feeble bands might fairly be compared with that of attempting to fix the azimuths of three terrestrial objects in dim twilight with a theodolite of which the telescope magnified seven times. Part of the inaccuracy is also probably due to the indeterminateness of the bands themselves.

Making due allowance for this uncertainty, it seems probable that the three "bright" bands of wave-lengths, 546·8, 514·0, and 489·2, are identical with the three brightest bands afterwards measured with the same apparatus in Mr. Gore's *Nova Orionis*, of which the brightest parts were at wave-lengths 542·8, 516·2, and 494·4.* The trace of a condensation of light at W.L. 471·6

* *Monthly Notices*, vol. xlvi. p. 110.

seen on September 20 agrees well with the bright line in *Nova Orionis* at W.L. 472·2; while the maximum of light in *Nova* item is the point laid down at 482·2 on September 10, which does not correspond to any known bright band in the spectra of variable stars; it was, however, entered in the note-book, in the terms already stated, as "a suspicion of a bright line, but hardly more." But if it does roughly represent the position of a "bright" line actually visible in the spectroscope, one would feel inclined to regard it as a trace of the F line.* On October 2 the spectrum presented the same appearance as on the preceding day. On October 19 it could be still noted as continuous, but not uniform, with the Vogel spectroscope.

Although the foregoing results differ widely from those obtained at Greenwich, and also at Yale College, as regards the three chief lines the observer cannot doubt as to their general correctness. The spectroscope was specially adapted to the work, the average thickness of the prism traversed by the light being less than $\frac{5}{16}$ inch, and the object-glasses of collimator and viewer were cemented so as to reduce the loss of light to a minimum. The arrangement of the tangent-screw is also such that the observer has the least possible idea as to the position of the lines measured until the divided head is read off. *E.g.*, in this particular instance of October 1, until the observations were ended, the observer had not the slightest suspicion that the "red" end of the spectrum was actually above the D lines. Besides, in the case of an object losing so rapidly its power of emitting light, it is quite possible that the spectrum may have slightly varied from day to day.

In conclusion, it seems worthy of remark that the spectrum described above is the same as that given by any ordinary hydro-carbon flame, burning so feebly that the spectrum of the blue base of the flame is just beginning to show through the continuous spectrum afforded by the white part of the flame.

### *Estimations of Magnitude.*

The earlier estimations were made either with the 6-inch Simms' telescope, power 28, or with a power of 24 on either of the two $3\frac{3}{4}$-inch finders of the 15-inch Equatorial. But about September 10 it was found that these low powers showed the new star relatively much brighter than did the large telescope, and a greater amplification. On trial it was found that this was because the low powers failed to separate the star sufficiently from the surrounding nebulosity; the image, therefore, which was compared wtth the neighbouring stars was made up of *Nova plus* the denser part of the nebula. In the 15-inch, on the other

* According to *Nature*, No. 837, p. 42, Mr. O. T. Sherman, of Yale College Observatory, has seen the bright F line in the spectrum of the Great Andromeda Nebula.

hand, *Nova's* image was not only quite distinct from that of the nebular nucleus, but the remainder of the nebula could be almost completely effaced by a suitable illumination of the field of view. Experimenting in this way on September 10, it turned out that *Nova* seen with a high power in a bright red field was of the 8·7 magnitude by comparison with neighbouring stars, or relatively $0^m \cdot 8$ fainter than when seen in the finder or the 6-inch, which *Andromedæ* at 544·4 on September 10 is closely in accord with that for the star in Orion at 542·8. The only really discordant showed it of the 7·9 magnitude. From this it would seem that the low powers and dark field included as much of the surrounding nebulosity along with *Nova* as would be equal to a star of the 8·6 magnitude; for on Pogson's scale

Light of $8^m \cdot 7$ star + light of $8^m \cdot 6$ star = light of $7^m \cdot 9$ star, nearly.

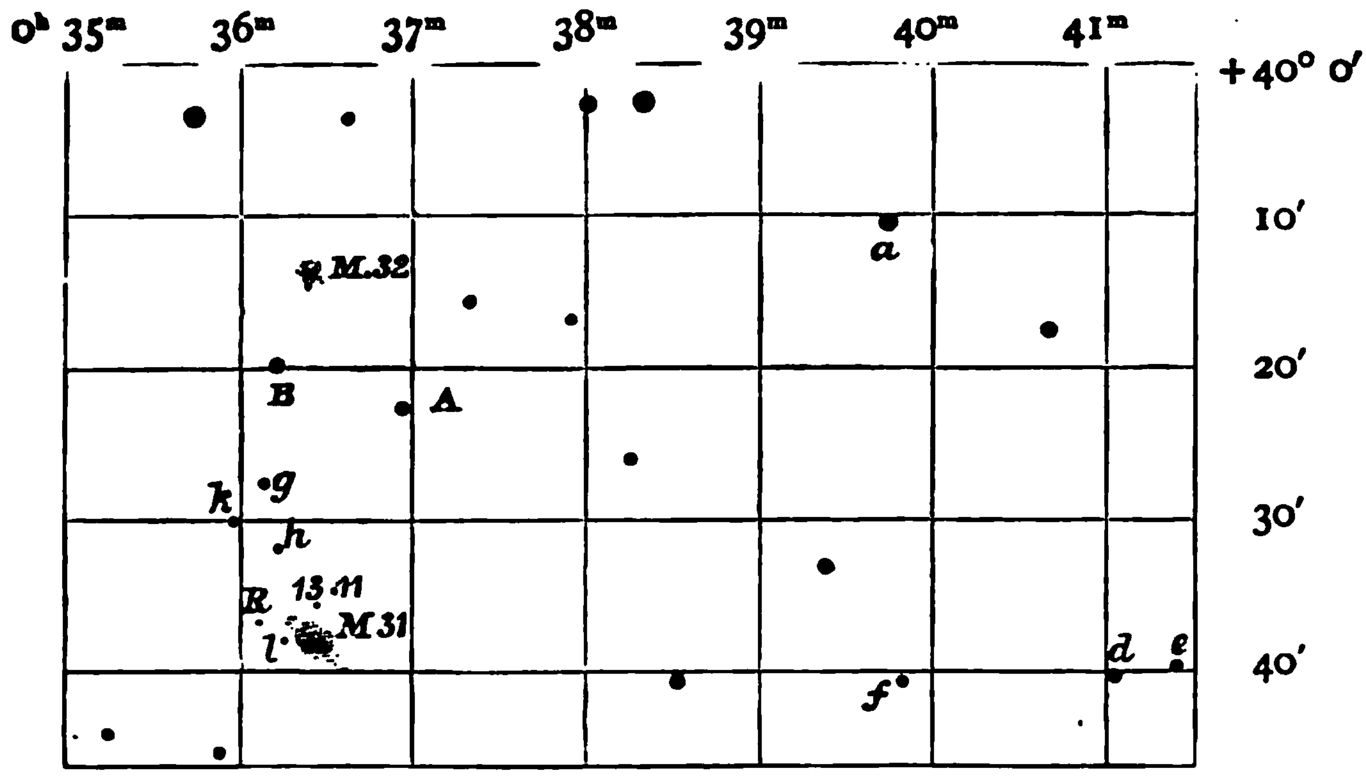
After this date, therefore, all the comparisons were made in a field bright enough to efface the diffused nebulosity, or, when the new star became fainter, with as much light as it would bear. The estimations were made on an arbitrary scale, of which it was found that $0^m \cdot 8$, or rather $0^m \cdot 79$, corresponded to one magnitude of Argelander's scale. The following is a list of all the stars used in direct comparison with *Nova* or the nucleus, or for fixing the scale of magnitudes; in particular A and B were used in checking the brightness of *g*, *h*, and *k*. The places are in part brought up from the *Durchmusterung*.*

| | α (1885·0.) h m s | δ (1885·0.) ° ′ | No. in D.M. | In D.M. | Magnitude Adopted. |
|---|---|---|---|---|---|
| *k* | 0 35 55·5 | +40 30·4 | | | 11·60 |
| R | 0 36 7·9 | 40 37·1 | | | (13 ±) |
| *g* | 0 36 9·7 | 40 27·8 | | | 10·63 |
| B | 0 36 12·8 | 40 19·7 | +40,145 | 9·0 | 9·1 |
| *h* | 0 36 14·9 | 40 32·3 | | | 10·95 |
| *l* | 0 36 17·1 | 40 38·0 | | | 11·60 |
| A | 0 36 57·9 | 40 22·8 | +40,149 | 9·1 | 9·0 |
| *a* | 0 39 44·6 | 40 10·7 | +40,158 | 7·5 | 7·60 |
| *f* | 0 39 49·2 | 40 40·8 | +40,159 | 9·5 | 9·42 |
| *d* | 0 41 2·3 | 40 40·3 | +40,161 | 9·1 | 9·01 |
| *e* | 0 41 25·1 | 40 39·8 | +40,162 | 9·1 | 9·18 |

The subjoined sketch contains all the D.M. stars near the

* R is a small star measured at Birr Castle on October 28, 1851, which, according to M. Trouvelot (*Comptes Rendus*, tome ci. p. 799), was not visible at Harvard College in 1874. It is at present (1886, December 6) of the 13th magnitude, and about equal to star 13, which is also wanting in M. Trouvelot's drawing. R appears as a comparatively bright star in the reproduction of Mr. Common's photograph in *Nature*, No. 831, which, however, does not give 13.

Great Nebula as well as those of the foregoing list, and the two small stars, 11 and 13, measured on October 2, 1885.




Stars near the Great Nebula in Andromeda: Epoch 1885·0
+ = Nova Andromedæ.

The stars $g$, B, $h$, $l$, and A are respectively identical with $a$, B, $\beta$, $\gamma$, and A of Mr. Stone's list in *Monthly Notices*, vol. xlvi. p. 57, but the magnitudes differ considerably towards the fainter end of the scale; *e.g.*, Mr. Stone's $\beta$, which is called $11^{m}{\cdot}4$ at Oxford, is barely $11^{m}{\cdot}0$ on the Dun Echt scale.

The following table shows the resulting magnitude of *Nova* for each night on which estimations were made:—

| Date. | | G.M.T. | Estimations with finder and 6-inch. | Magnitude. |
|---|---|---|---|---|
| | | h | m | m |
| 1885, Sept. | 1 | 8·9 | 7·68 | [8·47] |
| | 3 | 12·5 | 7·76 | [8·55] |
| | 5 | 13·2 | 7·84 | [8·63] |
| | 9 | 12·5 | 7·92 | [8·71] |
| | 10 | 10·2 | 7·92 | [8·71] |
| | 11 | 12·0 | | 8·85 |
| | 12 | 9·2 | | 8·97 |
| | 13 | ... | | 8·77 |
| | 15 | ... | | 9·17 |
| | 17 | ... | | 9·49 |
| | 19 | 9·3 | | 9·41 |
| | 29 | 11·6 | | 9·75 |
| | 30 | ... | | 9·83 |
| Oct. | 2 | 12·9 | | 9·91 |
| | 4 | 10·3 | | 10·39 |

| Date. | G.M.T. | Estimations with finder and 6-inch. | Magnitude. |
|---|---|---|---|
| | h | m | m |
| 1885, Oct. 5 | 13·5 | | 10·47 |
| 6 | 7·3 | - | 10·47 |
| 7 | 7·2 | | 10·47 |
| 19 | 7·8 | | 10·91 |
| Nov. 4 | 11·2 | | 10·95 |
| 5 | 11·8 | | 10·95 |
| 7 | 12·1 | | 10·95 |
| 30 | 10·1 | | 11·9 |
| Dec. 2 | 9·2 | | 12·1* |
| 29 | 10·1 | | 13·0 |
| 1886, Jan. 2 | 9·1 | | 13·5 |
| 30 | 11·2 Not certainly seen; $7\frac{1}{4}$ hours west of meridian. | | |
| 31 | 7·0 Just discernible; sky very clear ·$14^m$ ±. | | |
| Feb. 2 | 8·0 Not a trace of *Nova* with 15-inch aperture. | | |

These observations, plotted by themselves on cross-lined paper, would lead to the conclusion that *Nova* decreased continually but very irregularly, the light curve falling by a succession of steps. But on a comparison with the results of the eye-estimations at the Radcliffe Observatory, and the photometric results of Prof. Pritchard, M. Charlier, and Dr. Müller, this conclusion is not confirmed, the irregularities disappearing from the mean of all the observations. Even the very slow decrease between September 5 and 13, although confirmed by Dr. Hartwig's curve in *Ast. Nach.*, No. 2690, is not apparent in the mean of the other observations. The records agree best in showing that the star faded more rapidly at first than in the later stages of its disappearance.

*The Visibility of the Nebula.*

It has already been said that the nucleus of the Great Nebula was seen and measured on September 3. It was not seen on September 1, but there was so much cloud, and attention was so completely directed to the new star and its spectrum, that the relatively faint nucleus may have been simply overlooked, the more so as the greater brilliancy of *Nova* on that night must have overpowered it still more than on the 3rd. From the moment the nebular nucleus was discerned a look-out was naturally kept for the remaining features of the nebula. By September 10 a decrease of two or three tenths of a magnitude in *Nova* already permitted the innermost of Bond's dark lanes to be made out, the remoter parts of the nebula at the same time presenting their usual appearance. With power 307 the nucleus was estimated as 2″ in diam.$=11^m$ star; very sud-

* In dark field *Nova* about equal to the nucleus of the nebula, but a red field obliterates the nucleus, leaving *Nova* still clearly visible.

denly much brighter in the middle. With power 132 it was more gradually brighter in the middle. On October 5, with power 132, the nebula was splendidly visible, apparently as the observer had known it for more than twenty-five years. On November 5, 1885, the night being fine and the moon out of the way, a lengthy examination was made of the nucleus and the new star with eyepieces ranging from about 120 to 600 diameters, both with and without illumination of the field of view. The lenses of the lowest eyepiece are adjustable, so that its power varies to some extent. The appearances may be summarised as follows:—

*Without Illumination.*—With the lowest power the nucleus was stellar, and about 1 magnitude fainter than *Nova.* The nebulosity everywhere extended far beyond the field of view, except where Bond's dark lanes came in. Power 132 showed the nucleus barely different from a star of the 11th magnitude, and also with 229 the nucleus was fairly stellar, but with 307 this was no longer the case, the densest part appearing about 4″ in diameter. Increasing the power to 442 rendered the nucleus slightly more diffuse, and showed an elongation towards *Nova.* With this eyepiece *Nova* was still as sharp and distinct as any other star. Magnified about 600 times the nucleus was seen as a soft nebulosity 5″ in diameter.

*With bright Illumination of the Field.*—With a red field sufficiently bright to restrict the visible nebulosity to about 20″ diameter, the nucleus appeared quite stellar and one magnitude fainter than *Nova.* This was with the lowest eyepiece. Tried in the same way with powers 132 and 229 the nucleus did not appear nearly so star-like, and on increasing the illumination it almost disappeared, while *Nova* remained quite bright. With power 307, the red illumination not being quite strong enough to obliterate the nucleus, a bright yellow field was tried which completely overpowered the nucleus, while leaving the new star brightly visible. On applying power 442 with the same field, the nucleus appeared 4″ or 5″ in diameter, but was very sensitive to illumination, being extremely difficult to distinguish even when *Nova* was quite bright. With a power of 600 it was found that the nucleus disappeared before the star $11^s$ preceding.

The chief points believed to be shown by these experiments are:—the perfectly stellar character of *Nova* and the extreme sensitiveness of the Great Nebula and its nucleus to illumination. It therefore seems but reasonable to conclude that the invisibility of the nebula, and even of the nucleus, on September 1 was solely due to the overpowering light of the new star.

To test this point still further, a Zöllner's photometer was attached to the 15-inch on November 20 of this year. On contracting the aperture to 3·6 inches it was found that the *Durchmusterung* star + 40° 158, 7·5 magnitude, could be most perfectly counterfeited by the artificial star of the photometer. On bringing this artificial star in front of the Great Nebula, the nucleus gradually disappeared as the artificial star approached it. In point of fact, the nucleus of the Great Nebula required

the artificial star to be fully 75″ distant before becoming fairly defined. On the other hand the companion nebula, M. 32, bore the comparison star very much closer, say within 15″. Dr. L. Becker fully confirmed this experiment, which was repeated by recurring three times to the D.M. star. When the artificial star was placed exactly upon the nucleus it was surrounded by a soft nebulosity, without any distinctive features. This experiment seems conclusive as to the power of a 7½-magnitude star to completely obscure every trace of the central part of the Great Nebula in *Andromeda* without necessarily effecting any change in the nebula itself.* At the same time, it does not at all prove that no change took place in the nebula, but simply that it was impossible to observe any such change as long as the star was shining brightly. At Dun Echt, however, no traces of a permanent change brought about by the outburst of the new star have been detected in the nebula since the fading of the star. Nevertheless, the fact of the appearance of a similar star in the globular cluster M. 80 = G. C. 4173 = *h*. 3624, as observed by Prof. Auwers and Mr. Pogson in 1860, goes far towards showing a connection between these sudden outbreaks and their apparent surroundings. This was pointed out by the late C. G. Talmage at the conclusion of the reading of a Paper on the New Star at the meeting of the British Association at Aberdeen in September 1885, and also forms the subject of a communication to the *Astronomische Nachrichten* (No. 2715)† by Prof. Auwers. The spectrum of G. C. 4173, moreover, is known to be very faint and continuous from the observations of Lieut.-Col. Herschel in 1868 (see *Proc. Roy. Soc.*, vol. xvi. p. 453), and thus resembles that of the Great Nebula in *Andromeda*. The chief difference between the two nebulæ is that, while Sir J. Herschel's 20-foot telescope completely resolved G. C. 4173 on two occasions at the Cape of Good Hope, the great northern nebula has never shown more than very doubtful signs of resolvability. It may be remarked that the decadence of the *Nova* of 1860 was much more rapid than that of the recent star, for Prof. Auwers' figures show that it fell 3 magnitudes in about twenty days, while *Nova Andromedæ* required about eighty days to decrease to the same extent.

With regard to the reported occurrence of a fresh stellar outbreak in the nebula this autumn (*Astr. Nach.* No. 2755), it may be worth recording that M. 32 was very carefully examined on September 27, without anything being seen in the Great Nebula that appeared worthy of remark. On October 20, the

* It has since occurred to the writer that by using the electric light it may be possible to produce an artificial star sufficiently bright to permit of repeating this experiment with the full aperture of a 15-inch telescope. By a close reproduction of the appearance of the star and the nucleus as observed on September 3, 1885, the brightness of the star on that day may even yet be redetermined with some approach to accuracy, on the probable assumption that the nucleus has not changed.

† See also *Ast. Nach.* vol. liii. col. 293; vol. lviii. col. 374; and *Monthly Notices*, vol. xxi. p. 32.

distance of the nucleus from the small star so often mentioned was $125''\cdot16$, as a result of six settings; nor could a trace of anything, except the old nucleus, be seen near the centre of the nebulosity, with a power of 229 on the 15-inch. The nebula was also swept over with the 6-inch object-glass prism on October 22, when nothing was seen in the diffused image to indicate the presence of a star.

*Dun Echt Observatory:*
1886, *Dec.* 7.

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## *Formulæ for Binary Stars.* By J. E. Gore.

For the following binary stars, of which the observations are not yet sufficient for the calculation of a satisfactory orbit, I have computed, by the method of least squares, the following empirical formulæ for the calculation of an ephemeris. The positions of the stars are for 1880·0:—

Σ 3116.

R.A. $6^h\ 15^m\cdot9$, $-11°\ 42'$.

Magnitudes 6·2 and 10.

$$\theta = 21°\cdot89 + 0°\cdot1425\ (t-1850).$$

$$\rho = 4''\cdot14 - 0''\cdot018\ (t-1850).$$

45 Geminorum = OΣ 165.

R.A. $7^h\ 1^m\cdot5$, $+16°\ 8'$.

Magnitudes 5, 10·7.

$$\theta = 127°\cdot72 - 1°\cdot585\ (t-1850) - 0°\cdot00811\ (t-1850)^2.$$

$$\rho = 3''\cdot697 - 0''\cdot0434\ (t-1850).$$

9 Argûs = Burnham 101.

R.A. $7^h\ 46^m\ 13^s$, $-13°\ 35'$.

Magnitudes 5, 7.

$$\theta = 291°\cdot38 + 3°\cdot044\ (t-1875).$$

$$\rho = 0''\cdot517\ (1875).$$

Σ 1175.

R.A. $7^h\ 56^m\cdot1$, $+4°\ 30'$.

Magnitudes 7·8, 9·7.

$$\theta = 211°\cdot16 + 0°\cdot369\ (t-1850).$$

$$\rho = 1''\cdot949\ (1850).$$

Σ 1287.

R.A. $8^h\ 44^m\cdot9$, $+12°\ 35'$.

Magnitudes 8, 10·3.

$$\theta = 100°\cdot83 - 0°\cdot442\ (t-1850).$$

$$\rho = 1''\cdot675 + 0''\cdot013\ (t-1850).$$

Σ 1389.

R.A. $9^h\ 45^m \cdot 5$, $+27° \ 33'$.

Magnitudes 8, 9.

$\theta = 321° \cdot 87 - 0° \cdot 378\ (t - 1850)$.

$\rho = 1'' \cdot 86 + 0'' \cdot 0097\ (t - 1850)$.

OΣ 215.

R.A. $10^h\ 9^m \cdot 7$, $+18° \ 20'$.

Magnitudes 7, 7·2.

$\theta = 255° \cdot 60 - 1° \cdot 103\ (t - 1850)$.

$\rho = 0'' \cdot 445 + 0'' \cdot 0116\ (t - 1850)$.

Σ 1879.

R.A. $14^h\ 40^m \cdot 4$, $+10° \ 10'$.

Magnitudes 7·8, 8·8.

$\theta = 54° \cdot 64 - 0° \cdot 522\ (t - 1850)$.

$\rho = 0'' \cdot 716$ (1850).

Anon. Herculis = Gledhill 528.

R.A. $16^h\ 40^m \cdot 3$, $+43° \ 42'$.

Magnitudes 8, 8.

$\theta = 132° \cdot 93 - 2° \cdot 441\ (t - 1870)$.

$\rho = 0'' \cdot 957$ (1870) (distance diminishing).

Σ 2536.

R.A. $19^h\ 26^m\ 16^s$, $+17° \ 32'$.

Magnitudes 8, 11.

$\theta = 45° \cdot 29 + 0° \cdot 761\ (t - 1850)$.

$\rho = 1'' \cdot 852$.

OΣ 437.

R.A. $21^h\ 15^m \cdot 9$, $+31° \ 56'$.

Magnitudes 7, 10·5 (6·5, 7·2 Perrotin, 1885·720).

$\theta = 62° \cdot 53 - 0° \cdot 434\ (t - 1850)$.

$\rho = 1'' \cdot 34$ (1850) ($1'' \cdot 600$ Perrotin, 1885·720).

72 Pegasi = Burnham 720.

R.A. $23^h\ 28^m$, $+30° \ 40'$.

Magnitudes 6, 6·1.

$\theta = 310° \cdot 98 + 2° \cdot 229\ (t - 1880)$.

$\rho = 0'' \cdot 404$ (1880).

Formulæ for most of the other binary stars, computed by Drs. Doberck and Dunér, will be found in Gledhill's *Handbook of Double Stars*, and the "Corrections, Notes, &c.," to this excellent work.

## *Mr. Sherman's Observations of Bright Lines in Stellar Spectra.* By E. W. Maunder.

I fear, from Mr. Sherman's reply to my former Paper, that was not sufficiently explicit in my criticism of his observations, r he certainly seems to have missed the point of my remarks. or has he yet explained his method of procedure in such a way ıat I can understand it.

His object is "to render the image of the bright line light as road and intense as may be, and the intensity of the background ght a minimum." I see but one way of attaining this end: viz., y employing as high a dispersion as the star will bear, and by ıaking the spectrum as pure as possible by the use of a long ›llimator and narrow slit. Mr. Sherman has indeed employed fairly high dispersion, but so far as I can judge has made no fort to secure purity of spectrum.

We may take it that the image of a star in the primary focus a telescope is practically a point. The spectrum of a star is ıerefore a straight line, and as the image of the star has no very ›preciable breadth it is not necessary, in order to see the spec- um, to use a slit. The star will, as Mr. Sherman truly argues, ct as a slit for itself. If, then, certain radiations be missing in he star's light we shall have the coloured line of the star spec- um broken by dark points, each dark point being a negative nage of the star. If certain radiations in the star's light be ceedingly brilliant we shall have them appearing as bright oints on the coloured line of the star spectrum, each bright oint being an image of the star; and indeed the entire ›ntinuous spectrum is but a succession of an infinite number of arious coloured images of the star. By what means then does Ir. Sherman secure that his bright lines are of a *greater* breadth ıan the star spectrum when he uses no cylindrical lens, and of *less* breadth than the star spectrum when he broadens it out ıto a band by the use of a cylindrical lens?* How is it that they scape the broadening effect of the cylindrical lens whilst the ›ectrum on which they stand is widened out? It was this point ı particular which made me say (*Monthly Notices*, vol. xlvi. p. 283): It seems very difficult to believe that this can be a description f the behaviour of true stellar bright lines," and not the change- ble flickering appearance which Mr. Sherman ascribes to them, ıough I confess that, in my view, added to the unlikelihood of ıeir being true lines. My remarks as to the positions of the slit nd cylindrical lens were also directed to this point, as I thought possible that with a slit badly adjusted and the cylindrical lens lose to the eye, false images, produced within the spectroscope, ıight present the very appearance Mr. Sherman has described f long lines in the red, and stellar points in the green. Per-

* "At the red end, under a sharp focus, they (the bright lines) stand out ıe full breadth of the spectrum, bearing somewhat the same relation to the ıckground as the prominence to the solar spectrum. *In the brighter portion f the spectrum they are cut down to fine star-points.*"

sonally I much prefer the use of the cylindrical lens before the slit, but it is not *necessarily* wrong to use it close to the eye.

Mr. Sherman, whilst expanding my criticism as to the width of his slit, fails to see how it affects his measures. His slit was 6′ of arc in width, the diffraction disc of his star was, he adds, about 3″. The slit was therefore 120 times too wide at least, not merely 100 times, as I said. The purpose of a slit in stellar spectroscopy is twofold. It is not necessary in order to see the spectrum, but it is necessary to give it purity, and so to bring up fine lines. And it is absolutely essential for measures of position. Unless the slit is so nearly closed as just to hold the star between its jaws, what guarantee has the observer that the star is not travelling about from one side to the other of the slit? And if the star moves, the lines in its spectrum will move too. With a slit of the width recorded by Mr. Sherman no reliance whatsoever can be placed on the positions he records for the lines he observed, unless he can show that he had some means of absolutely fixing the star to one particular and invariable position. Then again, how did he obtain his fiducial points for the reduction of his observations? Did he allow the light from vacuum tube or taper to shine in through this wide slit, thus practically observing the comparison spectrum through a slit 120 times that of the stellar spectrum? Surely I was right in saying that such a slit was practically no slit at all. Mr. Sherman, for all that appears, might as well have removed his slit plates altogether.

I infer from the second paragraph on p. 18 in Mr. Sherman's reply that he wishes to withdraw his claim for some, if not for many, of the stars he has examined. I felt sure that more careful and continued observations would lead him to that conclusion.

Finally, I have no wish to say that in every case Mr. Sherman has been misled. I frankly confess that I do not think his observations look promising; but since we were both in pretty close accord as to our observations of *Nova Andromedæ*, he will, I hope, acquit me of any desire to pass a sweeping condemnation on his entire work.

With regard to the numerous quotations he has made from various observers, I trust that he will not do me the injustice of supposing that they were either unknown to or ignored by me. I do not, however, see how they bear upon the point at issue, which is, not whether bright lines have not been detected in a few special stellar spectra, but whether they form a prominent but hitherto unsuspected feature in every one of fifty stellar spectra taken at random; and whether true bright lines could behave as Mr. Sherman has described his lines as doing, viz. show themselves either as broader or narrower than the general stellar spectrum of which they formed a part.

*Royal Observatory, Greenwich:*
1886, *December* 10.

## *Observations of Comet f 1886 (Barnard), made at the Royal Observatory, Greenwich.*

*(Communicated by the Astronomer Royal.)*

The observations were made with the East or Sheepshanks Equatorial, aperture 6·7 inches, by taking transits over two cross-wires at right angles to each other, and each inclined 45° to the parallel of Declination.

*Comet f 1886.*

| 1886. | Greenwich Mean Solar Time. | Observer. | ☄ − ✱ R.A. | Corr. for Par. and Refract. in R.A. | ☄ − ✱ N.P.D. | Corr. for Par. and Refract. in N.P.D. | No. of Comp. | Apparent R.A. | Apparent N.P.D. | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | | m s | s | ′ ″ | ″ | | h m s | ° ′ ″ | |
| Nov. 17 | 18 0 31 | T. | +0 40·00 | −0·24 | + 8 24·5 | −6·1 | 2 | 13 11 48·72 | 77 6 50·5 | *a* |
| 17 | 18 1 30 | | −0 29·70 | −0·25 | − 2 22·5 | −6·5 | 1 | 13 11 50·29 | 77 6 23·3 | *b* |
| 18 | 17 5 26 | H. T. | −3 32·85 | −0·29 | − 1 5·6 | −6·3 | 6 | 13 18 35·82 | 76 41 14·9 | *c* |
| 30 | 17 25 57 | | +1 25·00 | −0·40 | + 7 21·4 | −6·6 | 3 | 15 7 23·80 | 72 17 52·0 | *d* |
| 30 | 17 48 7 | | +5 7·43 | −0·40 | − 2 28·8 | −7·5 | 3 | 15 7 33·93 | 72 17 26·6 | *e* |
| Dec. 2 | 17 55 49 | | −0 52·66 | −0·40 | + 4 11·0 | −7·1 | 8 | 15 29 30·29 | 72 1 55·4 | *f* |
| 7 | 5 29 34 | T. | +0 38·15 | +0·40 | − 4 39·5 | −7·8 | 4 | 6 19 45·65 | 72 17 2·1 | *g* |
| 7 | 5 34 45 | | −0 33·81 | +0·50 | − 8 36·8 | −8·4 | 10 | 16 19 47·89 | 72 17 11·4 | *h* |
| 9 | 17 5 3 | H. T. | +0 21·73 | −0·30 | +11 36·5 | −4·7 | 3 | 16 47 9·83 | 72 57 5·5 | *i* |

*Mean Places of Comparison Stars.*

| Star's Name. | R.A. 1886·0. h m s | N.P.D. 1886·0. ° ′ ″ | Authority. |
|---|---|---|---|
| *a* W.B. XIII. 151 | 13 11 8·05 | 76 58 22·9 | Weisse's Bessel |
| *b* W.B. XIII. 171 | 13 12 19·33 | 77 8 43·3 | ,, ,, |
| *c* W.B. XIII. 325 | 13 22 8·08 | 76 42 18·1 | Glasgow Catalogue |
| *d* W.B. (2) XV. 80 | 15 5 57·60 | 72 10 33·6 | Weisse's Bessel (2) |
| *e* W.B. (2) XIV. 1323–4 | 15 2 26·25 | 72 19 59·0 | ,, ,, |
| *f* $\tau^3$ Serpentis | 15 30 22·76 | 71 57 49·7 | Greenwich 9-year Catalogue |
| *g* W.B. (2) XVI. 532–3 | 16 19 6·49 | 72 21 51·4 | Weisse's Bessel |
| *h* W.B. (2) XVI. 563 | 16 20 20·53 | 72 25 58·6 | ,, ,, |
| *i* W.B. (2) XVI. 1419 | 16 46 57·77 | 72 45 38·0 | ,, ,, |

*Notes.*

The observations are corrected for parallax and refraction. The initials H. T. and T. are those of Mr. Turner and Mr. Thackeray respectively.

*Royal Observatory, Greenwich:*
1886, *December* 10.

## *Observations of Comet Winnecke 1886, made at Sydney Observatory with the 11½ Equatorial and filar micrometer.*

*(Communicated by H. C. Russell, B.A., Government Astronomer.)*

| Date 1886. | Sydney M.T. | Star's Name. | Comparison Stars. R.A. | Comparison Stars. N.P.D. | Diff. of Comet from Star. R.A. | Diff. of Comet from Star. N.P.D. | Comet's position. R.A. | Comet's position. N.P.D. | No. of Comp. |
|---|---|---|---|---|---|---|---|---|---|
| | h m s | | h m s | ° ′ ″ | m s | ′ ″ | h m s | ° ′ ″ | |
| Sept. 2 | 7 39 18 | 25809 Lalande | | | − 0 27·32 | +10 8·62 | | | 10 |
| 7 | 7 23 13 | 4777 B.A.C. | 14 19 7·81 | 102 50 10·98 | − 0 51·30 | + 2 36·99 | 14 18 16·51 | 102 52 47·97 | 3 |
| 8 | 7 35 32 | 5955 Wash. Gen. Cat. | 14 19 13·38 | 103 34 15·01 | + 3 26·80 | + 2 4·53 | 14 22 40·18 | 103 36 19·54 | 5 |
| 10 | 7 30 53 | 26481 Lalande | | | + 6 29·75 | − 4 9·45 | | | 2 |
| 11 | 7 35 33 | *27606 Lalande | 14 34 15·19 | 105 42 58·56 | + 1 52·34 | + 3 41·27 | 14 36 7·53 | 105 46 39·83 | 10 |
| 14 | 7 16 3 | 27033 Lalande | | | + 4 39·38 | + 4 22·73 | | | 10 |
| 15 | 7 31 24 | 27272 Lalande | | | + 1 44·25 | − 9 22·96 | | | 10 |
| 16 | 7 45 33 | 8261 Cape Cat. '80 | 15 5 44·70 | 109 21 33·39 | − 5 45·51 | + 4 12·89 | 14 59 59·19 | 109 25 46·28 | 8 |
| 17 | 7 28 40 | 27567 Lalande | | | + 1 37·38 | + 3 57·65 | | | 10 |
| 18 | 7 25 34 | 6282 Wash. Gen. Cat. | 15 12 10·60 | 110 41 11·47 | − 2 10·40 | +11 11·86 | 15 10 0·20 | 110 52 23·33 | 10 |
| 20 | 8 16 17 | 27980 Lalande | | | + 4 29·51 | − 9 28·14 | | | 7 |
| 20 | 8 57 44 | †8301 Cape Cat. '80 | 15 9 47·92 | 111 58 36·84 | +10 58·20 | +22 44·99 | 15 20 46·12 | 112 21 21·83 | 2 |
| 21 | 7 28 3 | 28282 Lalande | | | − 0 49·25 | − 3 27·84 | | | 10 |
| 22 | 8 15 8 | 8516 Cape Cat. '80 | 15 33 32·92 | 113 26 46·68 | − 2 12·66 | +18 59·32 | 15 31 20·26 | 113 45 46·00 | 5 |
| 23 | 7 34 18 | 8559 Cape Cat. '80 | 15 39 4·33 | 114 21 21·40 | − 2 21·18 | + 4 19·70 | 15 36 43·15 | 114 25 41·10 | 10 |
| 24 | 7 39 11 | 8628 Cape Cat. '80 | 15 46 47·47 | 114 59 7·31 | − 4 27·83 | + 8 7·86 | 15 42 19·64 | 115 7 15·17 | 10 |
| 25 | 7 33 52 | 8676 Cape Cat. '80 | 15 51 58·84 | 115 47 4·66 | − 3 58·30 | + 0 48·59 | 15 48 0·54 | 115 47 53·25 | 3 |
| 28 | 7 34 9 | 8807 Cape Cat. '80 | 16 5 18·41 | 117 37 44·10 | + 0 18·16 | + 8 42·33 | 16 36·57 | 117 46 26·43 | 10 |
| 29 | 7 31 2 | 8857 Cape Cat. '80 | 16 11 15·17 | 118 19 43·86 | + 0 23·19 | + 4 28·67 | 16 11 38·36 | 118 24 12·53 | 10 |

* This star was observed with the Sydney Transit Instrument on June 25, 1886.

† The difference between the comet and an 8½ mag. star first observed, then the difference between the 8½ mag. star and 8301 Cape Cat. '80.

1886, Sept. 1.—Comet seen; only approximate position obtained.

Sept. 2.—Comet very faint as close to moon; a diffused coma, no decided nucleus.

Sept. 8.—Strong moonlight; comet much more condensed than on Sept. 2. Coma small, about $\frac{1}{4}'$ in diam.

Sept. 9.—Comet much brighter even with increased moonlight; a suspicion of a nucleus. Observed with a star not in catalogue.

Sept. 10.—Comet extremely faint, and difficult to observe owing to haze.

Sept. 14.—Comet brighter; a suspicion of a nucleus.

Sept. 15.—Comet much brighter; coma about 1′ in diam.

Sept. 20.—Comet brighter; condensed in the centre, with a very faint nucleus.

Sept. 21.—Comet bright, but no very distinct nucleus, but condensed in the centre. At $8^h\ 2^m\ 13^s$ S.M.T. the centre of the comet passed over a 9-mag. star. The star did not diminish in brightness, but appeared to have a slight haze round it. Three other 9-mag. stars in the field. A very faint nucleus was thought to be seen in glimpses; but if there at all it must be very faint.

Sept. 22.—Comet not so bright as last night. Difference of declination determined by the circle.

Sept. 24.—Night particularly bad; comet much fainter than it has been. A glimpse of a nucleus.

Sept. 25.—Evening very hazy; haze stopped further observations.

Sept. 28.—Comet faint; coma diffused, with a faint nucleus.

Sept. 29.—Comet fainter.

Telescope $11\frac{1}{2}$-inch Equatorial, with filar micrometer.

*Observations of Comet discovered by Finlay at the Cape, Sept. 26, 1886, made at Sydney Observatory with the $11\frac{1}{2}$-inch Equatorial and filar micrometer.*

(*Communicated by H. C. Russell, B.A., Government Astronomer.*)

| Date. 1886. | Sydney M.T. | Star's Name. | Difference of Comet from Star. Comet−Star. R.A. | Comet−Star. N.P.D. | No. of Comp. |
|---|---|---|---|---|---|
| | h m s | | m s | ′ ″ | |
| Sept. 30 | 10 0 53 | 9391 Cape Cat. '80 | +1 45·7 | −7 44·51 | 1 |
| Oct. 1 | 8 48 47 | 9391 Cape Cat. '80 | +4 10·9 | −5 11·66 | 5 |
| 5 | 8 26 0 | 9504 Cape Cat. '80 | +4 12·70 | +13 40·92 | 6 |
| 11 | 9 17 49 | 9766 Cape Cat. '80 | −7 51·28 | −7 52·87 | 4 |
| 12 | 8 2 21 | 9766 Cape Cat. '80 | −4 57·38 | −6 59·78 | 10 |

Sept. 30.—Comet faint.

Oct. 5.—Moonlight; comet faint.

Oct. 7.—Comet observed with a star not in catalogue.

Oct. 8.—Comet brighter. At beginning of observations comet in a straight line with two 9-mag. stars. Change in R.A. during evening very apparent. Observed with a star not in catalogue.

Oct. 11.—Evening very hazy; comet very faint.

Oct. 12.—Comet faint.

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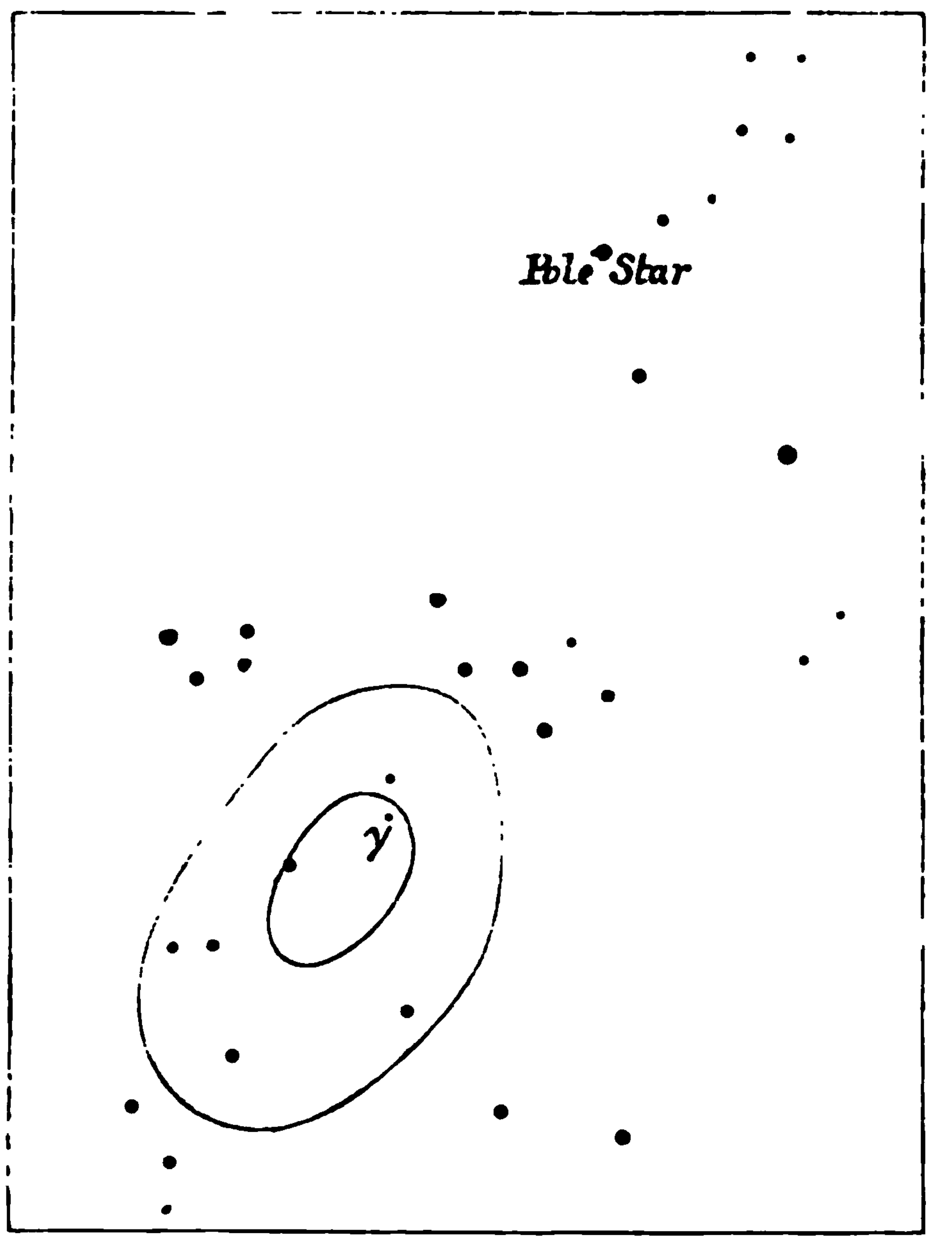
## *On Evidence with respect to the Form of the Area in the Heavens from which the Meteors of November 27, 1885, appeared to Radiate.* By A. C. Ranyard.

There were a great many observers of this rich shower, and most of them seem to agree that the meteors did not radiate from a point, but that there was a radiant area of some considerable extent. I did not observe the shower till well after its maximum at nearly nine o'clock; but from the forty or fifty meteors whose paths I observed, and was able to trace back upon the heavens (making a mental estimate of the distance of the radiant, judged from the length of the path and velocity), I thought that the area from which they radiated was elliptical, with its major axis nearly north and south, some 12° or 15° long, and a minor axis of 6° or 8°. I mentioned the elliptic shape of the area I had observed to Col. Tupman, and he told me that in the chart of paths he had laid down the radiant area was distinctly elliptical. But as I did not see any reason for such an elliptic form of the area, I regarded the coincidence as merely accidental, and thought that our results were probably not founded on a sufficient number of observed tracks. When Col. Tupman described his observations at the evening meeting of the Society, he stated that the longer axis of the elliptic area observed by him lay north and south. This struck me as an additional coincidence, for I felt sure that I had not mentioned to him the direction of the axes of the elliptic area observed by me; but I did not think seriously of the matter till a few weeks after, when I saw a letter from Prof. Young in *Nature* of December 17, in which, after describing his observations, he says that "the radiant was not a point but rather a region about 4° long north and south, and 2° wide." I then wrote to ask Prof. Young further about his observation, and he replied that the radiant region was "an oval area," perhaps a little larger than he had at first estimated.

Recently during a visit to the observatory at Nice, M. Perrotin showed me a map on which he and his assistants had laid down the courses of sixty or seventy meteors they had observed on the night of November 27. I at once saw that the paths did not radiate from a point, and without telling M. Perrotin of the other observations, I asked him to draw a contour line round the area of radiation. Both he and M. Thollon, who was present, drew elliptic curves with the longer axis north and south, or rather inclined 10° or 15° to the west of the north point.

The accompanying woodcut is made from the contour lines laid down by M. Perrotin and M. Thollon on a tracing from their map.




There therefore appears to be some very definite evidence that the paths of these meteors *did* radiate from an elongated area with its axis north and south. I have been thinking over the possible physical causes of such an elliptic area of radiation. If the paths of the meteors were all parallel they would appear to meet in a point. And if, on entering the earth's atmosphere, they were deflected from their original direction, and there was no greater tendency to deflection in one direction than in another, they would, on becoming luminous, move in paths which would be symmetrically arranged with respect to the original direction of motion, and an observer would refer them to a circular area of radiation with its centre corresponding to the original direction of motion outside the earth's atmosphere. If there were a greater tendency to scattering or "skidding" from the original direction of motion on entering the atmosphere in one direction rather than in the direction at right angles, the area of radiation would be elongated in the heavens in a direction corresponding with the direction of greatest "skidding." The elliptic area of radiation of the Biela meteors shows that their paths, at all events after they become luminous within the earth's atmosphere,

are not parallel, and that there is a greater tendency to deviate from the mean direction to the north and south than to the east and west.

It has been suggested by those who, like Sir Stawell Ball and Mr. Proctor, are inclined to believe that meteors were originally projected from the earth, that if they were ejected in slightly different directions they would not return moving in parallel paths; but if their paths outside the earth's atmosphere were not parallel, their orbits and their periods would be so very different that they would not come up to the earth again in a single swarm. We may therefore, I think, assume that the paths of the different components of a meteoric swarm are parallel in space before they encounter the earth's atmosphere, and that they are deflected by reason of their irregular shapes after they enter the earth's atmosphere, and usually before they become luminous, though there is abundant evidence that such deflection or "skidding" from their original course sometimes takes place after they become luminous. Professor Newton, Col. Tupman, and Mr. B. J. Hopkins have recorded meteors with curved paths. I have, on two occasions, seen meteors with curved paths, and there is a meteor with a very decidedly curved path in the chart of meteor tracks observed at Greenwich on the night of November 27, 1885, which is given at p. 62 of the December number of the *Monthly Notices* for 1885.

In order to account for the elliptic area, on the assumption that the deflection from the original path takes place within the earth's atmosphere, it is necessary to find some cause which would account for the deflection being greater in one plane than in the direction at right angles to it. This would be the case if there were some arrangement of the particles in space which caused them to set themselves with their longer axes north and south. I would suggest that if the particles are magnetic they would, on coming up to the earth, tend to arrange themselves with their longer axes parallel to the earth's magnetic axis. And in connection with this it is worth noticing that the axis of the contours drawn by M. Perrotin and M. Thollon do not point to the North Pole, but some 12° or 14° to the west of north, which about corresponds to the deviation of the magnetic meridian at Nice.

Neither Mr. Nash at Greenwich, who seems to have laid down with great care the tracks he gives in his chart, "principally from observations made between $8^h$ and $9^h\ 30^m$," nor Mr. Denning, whose attention was attracted by the large area of radiation, seem to have noticed its elliptic shape. But with such slow-moving meteors as those of the Biela swarm, the elliptic shape of the area above referred to would probably be missed by observers who combined tracks laid down with an interval of three or four hours. For, owing to the axial rotation of the earth, the centre of radiation would appear to shift rapidly in the heavens in a direction nearly at right angles to the longer axis of the observed

ellipse. Thus, by combining observations separated by a sufficient interval of time, a circular area of radiation might be deduced, though the true area of radiation for any instant was an ellipse of considerable ellipticity.

Mr. Denning appears to think that the radiant area of this shower was larger than that usually observed. He says:—"In many cases I found that very accurately observed paths deviated several degrees from the mean. The area of radiation must have been fully 7° in diameter to accommodate the discordances in the flights. The centre was at 24°+44°; but I saw several very short paths from a point south of γ *Andromedæ.*" This would seem to indicate that the radiant area was elongated in a north-westerly direction. Mr. Denning adds:—"I noted many of the meteors with the utmost care, in order to assure myself of the diffuseness of radiation, and it was found impossible to get a sharply defined position. The contrary effect was indeed so obvious as to arrest the eye whenever simultaneous bursts of about six or seven meteors took place near the radiant. It was then seen that the collective flights were not symmetrical emanations from a central point. They rather appeared to be discharged in a loose, disjointed fashion, from a comparatively large space on the N.W. region of γ *Andromedæ*, and just perhaps enveloping the star within its limits."

If the great extent of the radiant area should turn out to be peculiar to this shower, it would be evidence that the meteoric particles of the Biela stream are more irregular in shape than those of other streams. For example, one can conceive that they might be elongated crystalline forms, or a sponge-like meshwork of crystals containing magnetic iron, which has been torn into more than usually irregular shapes; or the irregular forms may be due to exposure to heat, which has evaporated volatile substances from the interstices of crystals with a higher melting point.

The size and shape of the area of radiation is well worthy of careful examination during future showers, noting the corresponding star magnitude of the meteor, observed beside each track laid down. Since the mass of similar-shaped meteoric particles varies as the cube of their diameter, while their resisting surface varies as the square of the diameter, we may expect to find the smaller particles heated to incandescence on entering the atmosphere more rapidly, and in a higher region, than larger masses, and the forces tending to deflect them from their original course bearing a larger proportion to the momentum the smaller the particle. It is probable that only the larger particles which enter the atmosphere become visible as naked-eye meteors, the dust-like particles being lost as telescopic meteors, or with a sudden spark, which, owing to distance and atmospheric absorption, may not be visible even as a telescopic meteor.

Some idea as to the size of meteoric particles capable of giving the light of a sixth-magnitude star may be derived from the

consideration that a standard candle, seen at the distance of a mile, is only a little brighter than a first-magnitude star. Consequently, without taking atmospheric absorption into account, an incandescent body at a distance of 100 miles would only appear as a sixth-magnitude star if it shone with a light about equal to that of an electric lamp of 100 candles power. As only the larger meteors enter the earth's atmosphere to a depth of below 70 miles above the surface, it may be assumed that few of the meteors seen, except those which appear in the zenith, approach within 100 miles of the observer. One may, consequently, pretty safely assume that a meteor which is just visible to the naked eye is larger than the portion of the carbons which is rendered incandescent in an arc-light of 100 candles power. For a mass of carbon such as is used for electric lighting purposes gives off more light while being driven into vapour than other substances which have been experimented upon; and the carbon of the electric light is not exposed to the tremendous bombardment of cold air, which must tend greatly to accelerate the disintegration of the meteoric particles in their passage through the air, as well as to cool their surface by removing the incandescent matter as rapidly as it is formed. If the above reasoning is correct, a much greater amount of matter must enter the Earth's atmosphere during a meteoric shower than has hitherto been supposed. Such matter would in time find its way to the Earth's surface, and when we consider geological periods of time, would have a sensible effect on the growth of the Earth, and the shape of continents.

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## *Note on an Erratic Meteor.* By B. J. Hopkins.

In November 1885 I had the honour of reading before the Society a Paper, containing a series of observations of mine of a class of meteors which from the apparent form of their paths I termed "erratic." I pointed out in that Paper that the appearance of these bodies was comparatively rare, and in proof of that statement I may here remark that, in a correspondence on the subject which I had with Mr. Denning, he informed me that, though he had observed considerably over 1,300 meteors during the year 1885, only four of them described paths similar to those mentioned in my Paper above referred to.

On account of their being so rarely seen, I have thought that a few remarks upon one I had the good fortune to observe on December 4, 18 hrs., would not be without interest; particularly as the meteor presented not only the peculiarity of a wavy path, but also had that path broken in two. The meteor referred to was of a brilliant white colour, and equalled *Jupiter* in apparent magnitude; it made its appearance near $\nu$ *Ursa Majoris*, and disappeared between $\iota$ *Draconis* and $\gamma$ *Ursa Minoris*.

The first portion of its flight extended from the point of its appearance to just beyond ζ *Ursa Majoris*, where it made a slight curve, the convex side of the curve being towards that star; at this point the train of light following the meteor in its flight divided, and the remainder of its path was continued at a short distance (about 30′) above the level—if I may use such a term—of the path pursued by it at its first appearance, though parallel to it. I have on one or two previous occasions noticed breaks in the path of a meteor, but never took any particular notice of it, looking upon it as merely an optical illusion; or the phenomenon has been so slight that I have not been able to decide whether I had actually seen it, or if it was due to fancy. Such an appearance as I have tried to describe would be caused, for instance, if at the point of disappearance of a meteor another made its appearance, and so as it were continued the path of the first. But in this case, owing to the brightness and slow motion of the meteor (it was visible for two seconds), and to the fact that I was looking at the part of the heavens in which it appeared at the moment it did so, thus having it in view from first to last, I can most confidently affirm that it was not an illusion due to the cause just mentioned, or to the imagination.

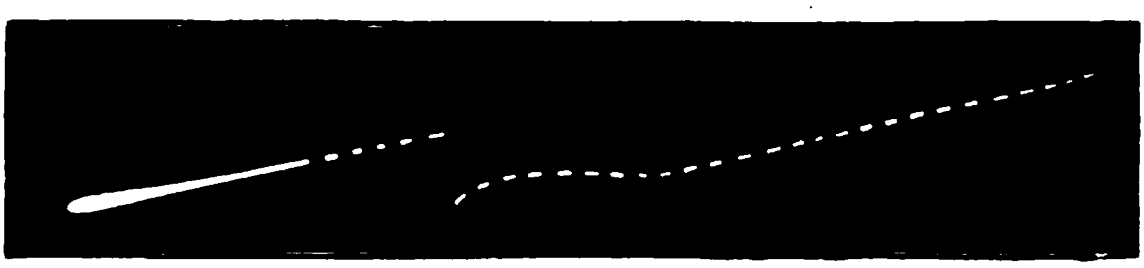

Diagram of Erratic and broken-pathed Meteor, 1886, Dec. 4.

A suggestion put forward, I believe, by Mr. Ranyard, during the discussion which followed the reading of my former Paper, viz., that the irregular shape of some meteors is the reason of their describing curved paths, will probably account for the slight curve I observed in the path of this meteor. But it is not so easy to explain the break in the path. Mr. Denning has observed meteors with divided paths, and accounts for them by ascribing the appearance as due to variations in the light of the meteor; this meteor did not, however, vary in brightness, and differed from those observed by Mr. Denning in that the second portion of its path was not in a line with the first. Whatever caused the meteor to change its course seems also to have been the cause of the momentary disappearance of the meteor, and it is in hopes of some explanation of the phenomenon being forthcoming that I venture to bring this observation before the notice of the Society.

*Forest Gate, E.:*
1886, *December* 9.

## *Ephemeris of the Satellites of Uranus*, 1887. By A. Marth.

P, angle of position of the minor axes of the apparent orbits.

$a$, $b$, major and minor semi-axes of the apparent orbits.

$u-U$, longitudes of the satellites in their orbits, reckoned from the points which are in superior conjunction with the planet or in opposition to the Earth.

U + 180°, planetocentric longitude of the Earth reckoned in the assumed plane of the orbits from the ascending node on the celestial equator.

B, planetocentric latitude of the Earth above the plane of the orbits, the ascending node N and inclination T in reference to the equator of 1880·0 are assumed to have the values

$$N = 165^\circ{\cdot}770 \qquad T = 75^\circ{\cdot}210$$

The corresponding values in reference to the plane of the orbit of *Uranus* are: long. of node 166°·005, inclination 98°·017, the long. of the node being reckoned along the planet's orbit from the point which precedes the ascending node of the planet's orbit on the ecliptic by its ecliptical longitude.

| Greenwich Noon. | | P | *Ariel.* $a_1$ | $b_1$ | $u_1-U$ | Diff. | *Umbriel.* $a_2$ | $b_2$ | $u_2-U$ | Diff. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1887. | | ° | ″ | ″ | ° | ° | ″ | ″ | ° | ° |
| Jan. | 13 | 284·388 | 14·62 | +6·42 | 346·06 | 1428·49 | 20·31 | +8·94 | 189·78 | 868·77 |
| | 23 | ·392 | 14·72 | 6·47 | 334·55 | ·46 | 20·50 | 9·02 | 338·55 | ·74 |
| Feb. | 2 | ·409 | 14·84 | 6·50 | 323·01 | ·43 | 20·68 | 9·06 | 127·29 | ·72 |
| | 12 | ·438 | 14·96 | 6·51 | 311·44 | ·40 | 20·84 | 9·07 | 276·01 | ·70 |
| | 22 | ·477 | 15·06 | 6·49 | 299·84 | ·37 | 20·98 | 9·04 | 64·71 | ·67 |
| Mar. | 4 | ·524 | 15·14 | 6·45 | 288·21 | ·35 | 21·10 | 8·98 | 213·38 | ·66 |
| | 14 | ·575 | 15·20 | 6·38 | 276·56 | ·32 | 21·18 | 8·89 | 2·04 | ·64 |
| | 24 | ·627 | 15·24 | 6·30 | 264·88 | ·29 | 21·23 | 8·77 | 150·68 | ·62 |
| Apr. | 3 | 284·679 | 15·24 | +6·19 | 253·17 | ·27 | 21·24 | +8·63 | 299·30 | ·61 |
| | 13 | ·729 | 15·22 | 6·08 | 241·44 | ·25 | 21·21 | 8·48 | 87·91 | ·61 |
| | 23 | ·774 | 15·18 | 5·97 | 229·69 | ·24 | 21·15 | 8·32 | 236·52 | ·59 |
| May | 3 | ·813 | 15·11 | 5·86 | 217·93 | ·23 | 21·05 | 8·16 | 25·11 | ·60 |
| | 13 | ·844 | 15·02 | 5·75 | 206·16 | ·22 | 20·93 | 8·01 | 173·71 | ·59 |
| | 23 | ·866 | 14·92 | 5·65 | 194·38 | ·22 | 20·78 | 7·87 | 322·30 | ·60 |
| June | 2 | ·880 | 14·80 | 5·57 | 182·60 | ·22 | 20·61 | 7·76 | 110·90 | ·60 |
| | 12 | ·885 | 14·67 | 5·50 | 170·82 | 1428·23 | 20·44 | 7·67 | 259·50 | 868·62 |
| | 22 | 284·881 | 14·54 | +5·46 | 159·05 | | 20·25 | +7·60 | 48·12 | |

| 1887. | | *Titania.* $a_3$ | $b_3$ | $u_3-U$ | Diff. | *Oberon.* $a_4$ | $b_4$ | $u_4-U$ | U | B |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ″ | ″ | ° | ° | ″ | ″ | ° | ° | ° |
| Jan. | 13 | 33·32 | +14·66 | 155·68 | 413·54 | 44·56 | +19·61 | 116·88 | 2·483 | +26·109 |
| | 23 | 33·63 | 14·79 | 209·22 | ·53 | 44·97 | 19·78 | 24·29 | 2·492 | 26·098 |
| Feb. | 2 | 33·92 | 14·86 | 262·75 | ·51 | 45·36 | 19·88 | 291·69 | 2·515 | 25·989 |
| | 12 | 34·19 | 14·88 | 316·26 | ·49 | 45·72 | 19·90 | 199·07 | 2·552 | 25·797 |
| | 22 | 34·42 | 14·83 | 9·75 | ·48 | 46·03 | 19·84 | 106·43 | 2·601 | 25·530 |
| Mar. | 4 | 34·60 | 14·73 | 63·23 | ·46 | 46·28 | 19·70 | 13·78 | 2·659 | 25·199 |
| | 14 | 34·74 | 14·58 | 116·69 | ·45 | 46·46 | 19·50 | 281·12 | 2·724 | 24·818 |
| | 24 | 34·82 | 14·38 | 170·14 | ·45 | 46·56 | 19·24 | 188·45 | 2·792 | 24·405 |
| Apr. | 3 | 34·83 | +14·15 | 223·59 | ·44 | 46·58 | +18·93 | 95·78 | 2·861 | +23·978 |
| | 13 | 34·79 | 13·90 | 277·03 | ·44 | 46·52 | 18·59 | 3·10 | 2·927 | 23·557 |
| | 23 | 34·69 | 13·64 | 330·47 | ·44 | 46·39 | 18·24 | 270·43 | 2·988 | 23·159 |
| May | 3 | 34·53 | 13·38 | 23·91 | ·45 | 46·18 | 17·89 | 177·76 | 3·040 | 22·801 |
| | 13 | 34·33 | 13·14 | 77·36 | ·45 | 45·90 | 17·57 | 85·09 | 3·083 | 22·498 |
| | 23 | 34·08 | 12·91 | 130·81 | ·46 | 45·58 | 17·27 | 352·44 | 3·114 | 22·262 |
| June | 2 | 33·81 | 12·72 | 184·27 | ·47 | 45·22 | 17·02 | 259·79 | 3·132 | 22·103 |
| | 12 | 33·52 | 12·57 | 237·74 | 413·48 | 44·83 | 16·81 | 167·16 | 3·136 | 22·027 |
| | 22 | 33·22 | +12·47 | 291·22 | | 44·43 | +16·67 | 74·53 | 3·127 | +22·038 |

The values of P, $a$, $b$ and $u$–U are to be interpolated directly for the times for which the apparent positions are required, the equation of light being already taken into account. The position-angles $p$ and distances $s$ are then found by means of the equations

$$s \sin (p-\mathrm{P}) = a \sin (u-\mathrm{U}),$$
$$s \cos (p-\mathrm{P}) = b \cos (u-\mathrm{U}).$$

The satellites move in the direction of increasing position-angles, and will be at their greatest elongations and at their conjunctions with the centre of the planet at the following hours, Greenwich mean time :—

*Ariel.*

| $p=$ | N. Elong. P+90° | | S. Elong. P−90° | | | N. Elong. | | S. Elong. | | | N. Elong. | | S. Elong. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1887 | | h | | h | | | h | | h | | | h | | h |
| | | | | | Mar. | 10 | 4·2 | 11 | 10·4 | April | 16 | 23·5 | 18 | 5·8 |
| Feb. | 2 | 21·3 | 4 | 3·6 | | 12 | 16·6 | 13 | 22·9 | | 19 | 12·0 | 20 | 18·3 |
| | 5 | 9·8 | 6 | 16·1 | | 15 | 5·1 | 16 | 11·4 | | 22 | 0·5 | 23 | 6·8 |
| | 7 | 22·3 | 9 | 4·6 | | 17 | 17·6 | 18 | 23·9 | | 24 | 13·0 | 25 | 19·3 |
| | 10 | 10·8 | 11 | 17·0 | | 20 | 6·1 | 21 | 12·4 | | 27 | 1·5 | 28 | 7·8 |
| | 12 | 23·3 | 14 | 5·5 | | 22 | 18·6 | 24 | 0·9 | | 29 | 14·0 | 30 | 20·3 |

| $p=$ | N. Elong. P+90° | S. Elong. P−90° | | N. Elong. | S. Elong. | | N. Elong. | S. Elong. |
|---|---|---|---|---|---|---|---|---|
| 1887 | h | h | | h | h | | h | h |
| Feb. | 15 11·8 | 16 18·0 | Mar. | 25 7·1 | 26 13·4 | May | 2 2·5 | 3 8·7 |
| | 18 0·3 | 19 6·5 | | 27 19·6 | 29 1·8 | | 4 15·0 | 5 21·2 |
| | 20 12·7 | 21 19·0 | | 30 8·1 | 31 14·3 | | 7 3·5 | 8 9·7 |
| | 23 1·2 | 24 7·5 | April | 1 20·6 | 3 2·8 | | 9 16·0 | 10 22·2 |
| | 25 13·7 | 26 20·0 | | 4 9·1 | 5 15·3 | | 12 4·5 | 13 10·7 |
| | 28 2·2 | M. 1 8·4 | | 6 21·6 | 8 3·8 | | 14 17·0 | 15 23·2 |
| Mar. | 2 14·7 | 3 20·9 | | 9 10·1 | 10 16·3 | | 17 5·5 | 18 11·7 |
| | 5 3·2 | 6 9·4 | | 11 12·6 | 13 4·8 | | 19 18·0 | 21 0·2 |
| | 7 15·7 | 8 21·9 | | 14 11·0 | 15 17·3 | | 22 6·5 | 23 12·7 |

*Umbriel.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Feb. | 1 13·7 | 3 15·4 | Mar. | 10 20·8 | 12 22·6 | April | 17 4·0 | 19 5·8 |
| | 5 17·2 | 7 18·9 | | 15 0·3 | 17 2·0 | | 21 7·5 | 23 9·3 |
| | 9 20·6 | 11 22·3 | | 19 3·8 | 21 5·5 | | 25 11·0 | 27 12·7 |
| | 14 0·1 | 16 1·8 | | 23 7·2 | 25 9·0 | | 29 14·5 | M. 1 16·2 |
| | 18 3·5 | 20 5·3 | | 27 10·7 | 29 12·4 | May | 3 17·9 | 5 19·7 |
| | 22 7·0 | 24 8·7 | | 31 14·2 | A. 2 15·9 | | 7 21·4 | 9 23·1 |
| | 26 10·4 | 28 12·2 | April | 4 17·6 | 6 19·4 | | 12 0·9 | 14 2·6 |
| Mar. | 2 13·9 | 4 15·6 | | 8 21·1 | 10 22·8 | | 16 4·3 | 18 6·1 |
| | 6 17·4 | 8 19·1 | | 13 0·6 | 15 2·3 | | 20 7·8 | 22 9·5 |

*Titania.*

| $p=$ | Super. Conj. P | | N. Elong. P+90° | | Infer. Conj. P−180° | | S. Elong. P−90° |
|---|---|---|---|---|---|---|---|
| | h | | h | | h | | h |
| Jan. | 26 15·5 | Jan. | 28 19·7 | Jan. | 31 0·0 | Feb. | 2 4·2 |
| Feb. | 4 8·4 | Feb. | 6 12·7 | Feb. | 8 16·9 | | 10 21·2 |
| | 13 1·4 | | 15 5·6 | | 17 9·9 | | 19 14·1 |
| | 21 18·3 | | 23 22·6 | | 26 2·8 | | 28 7·1 |
| Mar. | 2 11·3 | Mar. | 4 15·5 | Mar. | 6 19·8 | Mar. | 9 0·0 |
| | 11 4·3 | | 13 8·5 | | 15 12·7 | | 17 17·0 |
| | 19 21·2 | | 22 1·5 | | 24 5·7 | | 26 10·0 |
| | 28 14·2 | | 30 18·5 | April | 1 22·7 | April | 4 2·9 |
| April | 6 7·2 | April | 8 11·4 | | 10 15·7 | | 12 19·9 |
| | 15 0·2 | | 17 4·4 | | 19 8·6 | | 21 12·9 |
| | 23 17·1 | | 25 21·4 | | 28 1·6 | | 30 5·9 |
| May | 2 10·1 | May | 4 14·4 | May | 6 18·6 | May | 8 22·8 |
| | 11 3·1 | | 13 7·3 | | 15 11·6 | | 17 15·8 |
| | 19 20·1 | | 22 0·3 | | 24 4·6 | | 26 8·8 |
| | 28 13·0 | | 30 17·3 | June | 1 21·5 | June | 4 1·8 |

### *Oberon.*

| $p=$ | Super. Conj. P | N. Elong. | P+90° | Infer. Conj. | P−180° | S. Elong. | P−90° |
|---|---|---|---|---|---|---|---|
| 1887 | h | | h | | h | | h |
| Jan. 22 | 2·2 | Jan. 25 | 11·0 | Jan. 28 | 19·7 | Feb. 1 | 4·5 |
| Feb. 4 | 13·3 | Feb. 7 | 22·1 | Feb. 11 | 6·9 | 14 | 15·7 |
| 18 | 0·5 | 21 | 9·2 | 24 | 18·0 | 28 | 2·8 |
| Mar. 3 | 11·6 | Mar. 6 | 20·4 | Mar. 10 | 5·2 | Mar. 13 | 14·0 |
| 16 | 22·8 | 20 | 7·6 | 23 | 16·4 | 27 | 1·2 |
| 30 | 10·0 | April 2 | 18·8 | April 6 | 3·6 | April 0 | 12·4 |
| April 12 | 21·2 | 16 | 6·0 | 19 | 14·8 | 22 | 23·6 |
| 26 | 8·4 | 29 | 17·2 | May 3 | 2·0 | May 6 | 10·8 |
| May 9 | 19·6 | May 13 | 4·4 | 16 | 13·2 | 19 | 22·0 |
| 23 | 6·8 | 26 | 15·6 | 30 | 0·4 | June 2 | 9·2 |

*Titania* and *Oberon* will appear in the same direction from the centre of the planet February 3, $23^{h}\cdot5$; February 28, $14^{h}\cdot8$; March 25, $6^{h}\cdot1$; April 18, $21^{h}\cdot4$; May 13, $12^{h}\cdot7$; June 7, $4^{h}\cdot1$; and in opposite directions February 16, $7^{h}\cdot2$; March 12, $22^{h}\cdot4$; April 6, $13^{h}\cdot7$; May 1, $5^{h}\cdot0$; May 25, $20^{h}\cdot4$.

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Erratum, vol. xlvii. p. 9, 3rd line from bottom :—

*for* $\frac{e^4}{\lfloor 3}$ sin ²M, *read* $\frac{e^4}{\lfloor 3}$ sin 2M.

# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY.

VOL. XLVII. JANUARY 14, 1887. No. 3

J. W. L. GLAISHER, M.A., F.R.S., President, in the Chair.

Rev. W. Birks, Wanstead Villa, Villiers Road, Southsea;
Captain Thomas Exham, Officers' Club, Canute Road, Southampton;
Shelley Fisher, The Priory, Larkhall Rise, S.W.;
Cuthbert Hutchinson, Rock Lodge, Roker, Sunderland;
William Edward Jackson, Constantinople;
Captain Thomas Mackenzie, Royal Mail s.s. "Moselle," Southampton;
Horace Pearce, F.G.S., F.L.S., The Limes, Stourbridge; and
James Cruikshank Roger, The Grange, Walthamstow, Essex;

were balloted for and duly elected Fellows of the Society.

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*Observations of the Moon made at the Radcliffe Observatory, Oxford, during the year* 1886, *and a Comparison of the Results with the Tabular Places from Hansen's Lunar Tables.* By E. J. Stone, M.A., F.R.S.

The present Paper contains the Right Ascensions and North Polar Distances of the Moon as deduced from the observations made at the Radcliffe Observatory during the year 1886. These results are here compared with those deduced from Hansen's Lunar Tables on two suppositions:—

(1) That the mean times, found in the usual way from the sidereal times at mean noon given in the *Nautical Almanac*, were *not* changed in 1864.

(2) That the mean times *were* changed in 1864, in accordance with the views which I have explained in Papers already communicated to the Society.

For facilities for an accurate comparison between Hansen's Lunar Tables and Observations we are again indebted to the places published in the *Connaissance des Temps*.

TABLE I.

*Radcliffe Observations of the Moon*, 1886.

| Correction to be subtracted from M.T. for change of Sidereal Time at Mean Noon since 1864. | Day, 1886. | Observer. | Observed R.A. | Seconds of Hansen's R.A. | Hansen *minus* Observed. **Uncorrected** for Error in Time. | Correction due to Error in Time. | Hansen *minus* Observed. **Corrected** for Error in Time. | Observed N.P.D. | Seconds of Hansen's N.P.D. | Hansen *minus* Observed. **Uncorrected** for Error in Time. | Correction due to Error in Time. | Hansen *minus* Observed. **Corrected** for Error in Time. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s | | | h m s | s | s | s | s | ° ′ ″ | ″ | ″ | ″ | ″ |
| 32·77 | Jan. 13 | R. | 1 42 43·61 | 44·22 | +0·61 | −1·13 | −0·52 | 82 47 36·54 | 32·87 | −3·67 | +5·14 | +1·47 |
| 32·77 | 14 | W. | 2 35 15·17 | 15·81 | +0·64 | −1·19 | −0·55 | 79 3 23·17 | 19·32 | −3·85 | +4·68 | +0·83 |
| 32·77 | 15 | R. | 3 31 3·83 | 4·33 | +0·50 | −1·26 | −0·76 | 75 47 4·11 | 1·00 | −3·11 | +3·88 | +0·77 |
| 32·79 | 18 | R. | 6 39 11·33 | 12·04 | +0·71 | −1·45 | −0·74 | 71 37 18·45 | 16·69 | −1·76 | −0·72 | −2·48 |
| 32·79 | 19 | R. | 7 45 39·16 | 40·07 | +0·91 | −1·45 | −0·54 | 72 52 52·47 | 54·03 | +1·56 | −2·58 | −1·02 |
| 32·88 | Feb. 11 | W. | 3 9 2·33 | 3·00 | +0·67 | −1·20 | −0·53 | 77 9 16·05 | 13·89 | −2·16 | +4·13 | +1·97 |
| 32·93 | 23 | F.B. | 15 6 15·95 | 17·27 | +1·32 | −1·19 | +0·13 | 102 39 10·57 | 14·24 | +3·67 | −4·16 | −0·49 |
| 32·94 | 25 | R. | 16 53 13·22 | 14·48 | +1·26 | −1·17 | +0·09 | 107 14 32·31 | 35·33 | +3·02 | −1·88 | +1·14 |
| 33·01 | Mar. 15 | R. | 7 46 9·80 | 10·38 | +0·58 | −1·38 | −0·80 | 72 57 59·61 | 60·41 | +0·80 | −2·40 | −1·60 |
| 33·01 | 16 | W. | 8 48 35·22 | 36·12 | +0·90 | −1·37 | −0·47 | 75 22 44·65 | 48·38 | +3·73 | −3·94 | −0·21 |
| 33·02 | 17 | F.B. | 9 50 14·33 | 15·17 | +0·84 | −1·35 | −0·51 | 78 51 16·77 | 20·33 | +3·56 | −5·19 | −1·63 |
| 33·03 | 19 | R. | 11 49 33·45 | 34·28 | +0·83 | −1·29 | −0·46 | 87 49 5·18 | 10·27 | +5·09 | −6·36 | −1·27 |
| 33·04 | 23 | F.B. | 15 35 35·70 | 37·02 | +1·32 | −1·22 | +0·10 | 104 15 27·99 | 31·44 | +3·45 | −3·70 | −0·25 |
| 33·13 | April 15 | W. | 11 22 57·39 | 58·28 | +0·89 | −1·27 | −0·38 | 85 36 32·83 | 36·33 | +3·50 | −6·16 | −2·66 |
| 33·25 | May 14 | R. | 12 54 6·09 | 6·87 | +0·78 | −1·22 | −0·44 | 93 3 34·16 | 38·72 | +4·56 | −6·09 | −1·53 |
| 33·25 | 15 | F.B. | 13 48 56·08 | 57·18 | +1·10 | −1·22 | −0·12 | 97 27 30·09 | 34·93 | +4·84 | −5·63 | −0·79 |

| Correction to be subtracted from M.T. for change of Sidereal Time at Mean Noon since 1864. (s) | Day, 1886. | Observer. | Observed R.A. (h m s) | Seconds of Hansen's R.A. (s) | Hansen *minus* Observed. **Uncorrected** for Error in Time. (s) | Correction due to Error in Time. (s) | Hansen *minus* Observed. **Corrected** for Error in Time. (s) | Observed N.P.D. (° ′ ″) | Seconds of Hansen's N.P.D. (″) | Hansen *minus* Observed. **Uncorrected** for Error in Time. (″) | Correction due to Error in Time. (″) | Hansen *minus* Observed. **Corrected** for Error in Time. (″) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33.27 | May 18 | W. | 16 35 18.29 | 19.69 | +1.40 | −1.24 | +0.16 | 106 57 21.00 | 22.57 | +1.57 | −2.50 | −0.93 |
| 33.38 | June 15 | W. | 17 9 4.71 | 5.92 | +1.21 | −1.23 | −0.02 | 107 56 14.29 | 15.38 | +1.09 | −1.76 | −0.67 |
| 33.49 | July 12 | R. | 16 50 56.44 | 57.47 | +1.03 | −1.22 | −0.19 | 107 21 30.94 | 32.87 | +1.93 | −2.23 | −0.30 |
| 33.49 | 14 | F.B. | 18 39 6.98 | 8.08 | +1.10 | −1.21 | −0.11 | 108 44 24.93 | 24.34 | −0.59 | +0.37 | −0.22 |
| 33.50 | 15 | F.B. | 19 32 7.40 | 8.67 | +1.27 | −1.18 | +0.09 | 108 0 28.00 | 25.90 | −2.10 | +1.59 | −0.51 |
| 33.51 | 17 | F.B. | 21 13 58.17 | 59.61 | +1.44 | −1.12 | +0.32 | 104 4 48.16 | 44.41 | −3.75 | +3.59 | −0.16 |
| 33.52 | 20 | R. | 23 36 50.09 | 51.18 | +1.09 | −1.05 | +0.04 | 94 0 33.29 | 30.72 | −2.57 | +5.22 | +2.65 |
| 33.61 | Aug. 11 | W. | 19 15 5.48 | 6.67 | +1.19 | −1.18 | +0.01 | 108 17 33.79 | 33.65 | −0.14 | +1.17 | +1.03 |
| 33.61 | 13 | W. | 20 57 25.08 | 26.20 | +1.12 | −1.13 | −0.01 | 104 56 8.29 | 5.53 | −2.76 | +3.28 | +0.52 |
| 33.64 | 20 | F.B. | 2 31 43.95 | 44.95 | +1.00 | −1.14 | −0.14 | 79 58 35.59 | 32.29 | −3.30 | +4.77 | +1.47 |
| 33.71 | Sept. 7 | R. | 18 58 9.93 | 10.94 | +1.01 | −1.20 | −0.19 | 108 29 50.55 | 51.73 | +1.18 | +0.78 | +1.96 |
| 33.73 | 10 | W. | 21 30 32.34 | 33.45 | +1.11 | −1.11 | 0.00 | 103 9 24.48 | 22.32 | −2.16 | +3.85 | +1.69 |
| 33.73 | 11 | R. | 22 18 45.79 | 46.63 | +0.84 | −1.08 | −0.24 | 100 4 15.68 | 10.81 | −4.87 | +4.54 | −0.33 |
| 33.74 | 13 | W. | 23 52 55.22 | 56.56 | +1.34 | −1.06 | +0.28 | 92 44 27.02 | 23.58 | −3.44 | +5.33 | +1.89 |
| 33.75 | 15 | W. | 1 27 17.77 | 18.92 | +1.15 | −1.09 | +0.06 | 84 50 46.47 | 42.60 | −3.87 | +5.30 | +1.43 |
| 33.75 | 16 | R. | 2 15 59.36 | 60.41 | +1.05 | −1.12 | −0.07 | 81 4 44.89 | 41.81 | −3.08 | +4.94 | +1.86 |
| 33.75 | 17 | W. | 3 6 27.27 | 28.49 | +1.22 | −1.17 | +0.05 | 77 39 46.36 | 43.98 | −2.38 | +4.33 | +1.95 |
| 33.82 | Oct. 4 | R. | 18 38 41.48 | 42.59 | +1.11 | −1.23 | −0.12 | 108 44 13.39 | 14.35 | +0.96 | +0.33 | +1.29 |
| 33.84 | 8 | R. | 22 2 9.21 | 10.29 | +1.08 | −1.09 | −0.01 | 101 15 23.86 | 20.40 | −3.46 | +4.35 | +0.89 |

| Correction to be subtracted from M.T. for change of Sidereal Time at Mean Noon since 1864. | Day, 1886. | | Observer. | Observed R.A. | Seconds of Hansen's R.A. | Hansen *minus* Observed. **Uncorrected** for Error in Time. | Correction due to Error in Time. | Hansen *minus* Observed. **Corrected** for Error in Time. | Observed N.P.D. | Seconds of Hansen's N.P.D. | Hansen *minus* Observed. **Uncorrected** for Error in Time. | Correction due to Error in Time. | Hansen *minus* Observed. **Corrected** for Error in Time. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| s | | | | h m s | s | s | s | s | ° ′ ″ | ″ | ″ | ″ | ″ |
| 33·85 | Oct. | 11 | R. | 0 23 41·56 | 42·43 | +0·87 | −1·08 | −0·21 | 90 8 28·22 | 23·68 | −4·54 | +5·50 | +0·96 |
| 33·86 | | 13 | F.B. | 1 59 56·03 | 57·30 | +1·27 | −1·13 | +0·14 | 82 12 44·46 | 40·54 | −3·92 | +5·19 | +1·27 |
| 33·93 | Nov. | 1 | R. | 19 10 4·62 | 5·88 | +1·26 | −1·24 | +0·02 | 108 38 45·57 | 44·85 | −0·72 | +1·08 | +0·36 |
| 33·94 | | 2 | W. | 20 3 20·88 | 21·97 | +1·09 | −1·19 | −0·10 | 107 24 16·13 | 11·35 | −4·78 | +2·29 | −2·49 |
| 33·95 | | 5 | R. | 22 31 49·12 | 50·18 | +1·06 | −1·09 | −0·03 | 99 22 22·56 | 18·54 | −4·02 | +4·77 | +0·75 |
| 33·96 | | 8 | R. | 0 52 52·63 | 53·57 | +0·94 | −1·09 | −0·15 | 87 44 23·14 | 18·64 | −4·50 | +5·59 | +1·09 |
| 33·97 | | 9 | W. | 1 41 13·85 | 14·95 | +1·10 | −1·12 | −0·02 | 83 42 20·76 | 18·06 | −2·70 | +5·44 | +2·74 |
| 34·05 | Dec. | 1 | F.B. | 21 23 49·37 | 50·65 | +1·28 | −1·14 | +0·14 | 104 5 47·60 | 45·37 | −2·23 | +3·85 | +1·62 |
| 34·06 | | 2 | R. | 22 12 36·64 | 37·72 | +1·08 | −1·10 | −0·02 | 101 1 34·56 | 30·42 | −4·14 | +4·57 | +0·43 |
| 34·06 | | 3 | W. | 22 59 57·40 | 58·49 | +1·09 | −1·07 | +0·02 | 97 30 33·12 | 30·25 | −2·87 | +5·09 | +2·22 |
| 34·07 | | 4 | F.B. | 23 46 32·35 | 33·37 | +1·02 | −1·07 | −0·05 | 93 40 47·51 | 44·27 | −3·24 | +5·44 | +2·20 |
| 34·08 | | 7 | W. | 2 9 26·08 | 27·02 | +0·94 | −1·15 | −0·21 | 81 38 4·42 | 0·67 | −3·75 | +5·31 | +1·56 |
| 34·09 | | 9 | W. | 3 54 44·79 | 45·70 | +0·91 | −1·27 | −0·36 | 74 48 9·89 | 6·06 | −3·83 | +3·86 | +0·03 |
| 34·09 | | 10 | R. | 4 51 47·64 | 48·67 | +1·03 | −1·33 | −0·30 | 72 24 47·87 | 45·61 | −2·26 | +2·64 | +0·38 |
| Mean of Errors without regard to sign ... | | | ... | ... | ... | 1·032 s | ... | 0·225 s | ... ... | ... | 2·960″ | ... | 1·224″ |
| Mean Errors for Year | ... | ... | ... | ... | ... | +1·032 | ... | −0·158 | ... ... | ... | ... | ... | ... |

Observers: W., Mr. W. Wickham; R., Mr. W. H. Robinson; F.B., Mr. F. A. Bellamy.

TABLE II.

*Radcliffe Observations of the Moon, 1886.*

*Errors of the Moon's Tabular Place in Longitude and Ecliptic Polar Distance, "Uncorrected" and "Corrected" for the change in Mean Time introduced in 1864.*

| Day. | | Errors of Longitude (Hansen *minus* Observed.) | | Errors of E.N.P.D. (Hansen *minus* Observed.) | |
|---|---|---|---|---|---|
| | | **Uncorrected.** | **Corrected.** | **Uncorrected.** | **Corrected.** |
| 1886. Jan. | 13 | + 9″80 | − 7″76 | −0″16 | −1″41 |
| | 14 | +10·18 | − 7·97 | −0·73 | −1·73 |
| | 15 | + 7·83 | −10·95 | −1·28 | −1·90 |
| | 18 | + 9·99 | −10·71 | −2·46 | −1·74 |
| | 19 | +13·16 | − 7·82 | −0·79 | +0·37 |
| Feb. | 11 | +10·05 | − 8·02 | +0·57 | −0·20 |
| | 23 | +19·66 | + 1·70 | −1·79 | −0·99 |
| | 25 | +18·32 | + 1·41 | +0·96 | +0·99 |
| March | 15 | + 8·35 | −11·61 | −0·69 | +0·47 |
| | 16 | +13·62 | − 6·65 | +0·10 | +1·62 |
| | 17 | +12·86 | − 7·63 | −0·80 | +0·99 |
| | 19 | +13·44 | − 6·83 | −0·29 | +1·58 |
| | 23 | +19·53 | + 1·36 | −1·15 | −0·58 |
| April | 15 | +13·61 | − 6·27 | −2·00 | −0·21 |
| May | 14 | +12·56 | − 6·68 | −0·32 | +1·14 |
| | 15 | +17·05 | − 1·95 | −1·30 | −0·10 |
| | 18 | +20·18 | + 2·15 | −1·33 | −1·25 |
| June | 15 | +17·36 | − 0·34 | −0·41 | −0·64 |
| July | 12 | +14·92 | − 2·75 | +0·16 | +0·03 |
| | 14 | +15·67 | − 1·55 | +0·49 | −0·33 |
| | 15 | +18·26 | + 1·35 | +0·74 | −0·30 |
| | 17 | +21·14 | + 4·50 | +2·68 | +1·24 |
| | 20 | +16·00 | − 0·50 | +4·11 | +2·67 |
| Aug. | 11 | +16·87 | + 0·01 | +2·07 | +1·04 |
| | 13 | +16·36 | − 0·28 | +1·89 | +0·46 |
| | 20 | +15·12 | − 2·44 | +1·52 | +0·74 |
| Sept. | | +14·22 | − 2·89 | +2·62 | +1·68 |
| | 10 | +16·08 | − 0·53 | +3·08 | +1·60 |
| | 11 | +13·34 | − 3·19 | −0·09 | −1·58 |

| Day. | | Errors of Longitude (Hansen *minus* Observed.) Uncorrected. | Corrected. | Errors of E.N.P.D. (Hansen *minus* Observed) Uncorrected | Corrected. |
|---|---|---|---|---|---|
| 1886. | | ″ | ″ | ″ | ″ |
| Sept. | 13 | +19·80 | + 3·10 | +4·85 | +3·40 |
| | 15 | +17·44 | + 0·30 | +2·77 | +1·66 |
| | 16 | +15·75 | − 1·60 | +2·24 | +1·41 |
| | 17 | +17·90 | + 0·17 | +2·63 | +2·08 |
| Oct. | 4 | +15·73 | − 1·79 | +2·00 | +1·17 |
| | 8 | +16·09 | − 0·45 | +2·25 | +0·78 |
| | 11 | +13·82 | − 3·28 | +0·99 | −0·36 |
| | 13 | +19·12 | + 1·51 | +2·84 | +1·91 |
| Nov. | 1 | +17·93 | + 0·24 | +1·43 | +0·39 |
| | 2 | +16·27 | − 0·89 | −1·48 | −2·73 |
| | 5 | +16·06 | − 0·69 | +2·06 | +0·53 |
| | 8 | +14·77 | − 2·50 | +1·32 | +0·13 |
| | 9 | +16·31 | − 1·27 | +3·38 | +2·45 |
| Dec. | 1 | +18·40 | + 1·44 | +3·64 | +2·17 |
| | 2 | +16·34 | − 0·43 | +1·78 | +0·30 |
| | 3 | +16·08 | − 0·58 | +3·60 | +2·16 |
| | 4 | +15·31 | − 1·56 | +3·10 | +1·72 |
| | 7 | +14·44 | − 3·47 | +1·17 | +0·42 |
| | 9 | +13·71 | − 5·11 | −1·01 | −1·05 |
| | 10 | +14·96 | − 4·32 | −0·53 | −0·12 |
| **Mean of Errors, without regard to sign** | ... | **15″·342** | **3″·316** | **1″·666** | **1″·158** |
| **Mean Errors for Year** | | **+15″·342** | **−2″·531** | ... | ... |

TABLE III.

*Mean Excess over Observation of the "Moon's Tabular Place in Longitude," for the Years* 1847 *to* 1886, *as computed from Hansen's Tables.*

*"Uncorrected" and "Corrected" on and after* 1864 *for the change in Mean Tabular Time introduced in the year* 1884.

| Year. | Errors of Longitude (Hansen *minus* Observed.) Uncorrected. | Corrected. | Year. | Errors of Longitude. (Hansen *minus* Observed.) Uncorrected. | Corrected. |
|---|---|---|---|---|---|
| | ″ | ″ | | ″ | ″ |
| 1847 | +1·07 | +1·07 | 1852 | − 0·92 | −0·92 |
| 1848 | +0·20 | +0·20 | 1853 | − 1·63 | −1·63 |
| 1849 | −0·47 | −0·47 | 1854 | − 1·68 | −1·68 |
| 1850 | −0·28 | −0·28 | 1855 | − 0·87 | −0·87 |
| 1851 | −1·29 | −1·29 | 1856 | − 0·96 | −0·96 |

| Year. | Errors of Longitude (Hansen *minus* Observed.) Uncorrected. | Corrected. |
|---|---|---|
| 1857 | −1″·86 | −1″·86 |
| 1858 | −1·98 | −1·98 |
| 1859 | −1·80 | −1·80 |
| 1860 | −2·90 | −2·90 |
| 1861 | −2·19 | −2·19 |
| 1862 | −2·83 | −2·83 |
| 1863 | −1·61 | −1·61 |
| 1864 | +0·12 | −0·81 |
| 1865 | +1·27 | −0·22 |
| 1866 | +2·14 | −0·22 |
| 1867 | +3·48 | +0·36 |
| 1868 | +4·12 | +0·28 |
| 1869 | +4·28 | −0·35 |
| 1870 | +4·83 | −0·66 |
| 1871 | +6·96 | +0·44 |
| 1872 | +7″·31 | +0″·10 |
| 1873 | +8·24 | +0·20 |
| 1874 | +9·29 | +0·56 |
| 1875 | +9·87 | +0·36 |
| 1876 | +9·80 | −0·51 |
| 1877 | +9·23 | −1·90 |
| 1878 | +8·22 | −3·60 |
| 1879* | +9·63 | −3·12 |
| 1880 | +10·89 | −2·77 |
| 1881 | +10·51 | −4·06 |
| 1882† | +12·68 | −2·51 |
| 1883 | +14·71 | −1·50 |
| 1884 | +14·65 | −1·91 |
| 1885 | +15·14 | −1·87 |
| 1886‡ | +15·34 | −2·53 |

*Radcliffe Observatory, Oxford:*
1887, *January* 4.

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## *Mean Right Ascensions of Polaris, Cephei* 51 *(Hev.), δ Ursæ Minoris, and λ Ursæ Minoris for the year* 1887, *from the Radcliffe Observations of the years* 1880 *to* 1886. By E. J. Stone, M.A., F.R.S.

From the year 1880 to the year 1886 the azimuth errors of the Transit Circle at the Radcliffe Observatory have been based on the *Nautical Almanac* places of the stars *Polaris, Cephei* 51 (*Hev.*), *δ Ursæ Minoris, λ Ursæ Minoris,* after the application of corrections kindly furnished by the Astronomer Royal from year to year. The azimuth errors thus found agree well *inter se,* except those found from *Polaris* and *Polaris* S. P., which differ more than is desirable from each other and from the results found from observations of the other three stars. It has, therefore, been thought necessary to collect the results. It will be seen that the Right Ascensions of the Radcliffe Observations agree remarkably closely with the corrected *Nautical Almanac* places given by the Astronomer Royal for the three stars, *Cephei* 51, *δ Ursæ Min.*, and *λ Ursæ Min.*, but that the resulting Right Ascensions of *Polaris* agree much more closely with the tabular Right Ascensions of the *Berliner Jahrbuch*.

* All to 1879, Greenwich Observations.
† 1880 to 1882, Mean of Greenwich and Radcliffe.
‡ 1883 and since, Radcliffe only.

The resulting Right Ascensions for 1887 will be employed in the reductions of the Radcliffe Observations during the year 1887.

*Annual Results reduced to* 1887.

| Year. | Mean R.A. from Radcliffe Observations reduced to 1887. | Number of Observations. | Adopted Proper Motion. |
|---|---|---|---|
| | *Polaris.* | | |
| | h m s | | s |
| 1880 | 1 17 20·84 | 15 | +0·1179 |
| 1881 | 21·55 | 24 | |
| 1882 | 21·75 | 67 | |
| 1883 | 21·18 | 62 | |
| 1884 | 21·92 | 52 | |
| 1885 | 21·68 | 83 | |
| 1886 | 21·72 | 49 | |
| | *Cephei* 51 (*Hev.*). | | |
| 1880 | 6 47 16·38 | 9 | −0·0385 |
| 1881 | 16·42 | 31 | |
| 1882 | 16·39 | 24 | |
| 1883 | 16·56 | 27 | |
| 1884 | 16·44 | 37 | |
| 1885 | 16·43 | 21 | |
| 1886 | 16·75 | 21 | |
| | δ *Ursæ Minoris.* | | |
| 1880 | 18 8 46·18 | 5 | +0·0285 |
| 1881 | 45·66 | 25 | |
| 1882 | 45·71 | 21 | |
| 1883 | 45·75 | 20 | |
| 1884 | 46·01 | 30 | |
| 1885 | 45·93 | 17 | |
| 1886 | 45·97 | 28 | |
| | λ *Ursæ Minoris.* | | |
| 1880 | 19 36 53·24 | 3 | −0·0500 |
| 1881 | 47·31 | 26 | |
| 1882 | 47·50 | 25 | |
| 1883 | 48·38 | 19 | |
| 1884 | 47·68 | 21 | |
| 1885 | 47·35 | 11 | |
| 1886 | 48·53 | 4 | |

*Comparison of Mean Results with Tabular Right Ascensions.*

| Name of Star. | Mean of R.A. from Radcliffe Observations reduced to 1887. | Tabular R.A. from the *Nautical Almanac* for 1887. | Tabular R.A. from Greenwich Clock star list for 1887. | Tabular R.A. from *Berliner Jahrbuch* for 1887. |
|---|---|---|---|---|
| | h m s | h m s | h m s | h m s |
| Polaris | 1 17 21·60 | 1 17 19·63 | 1 17 20·00 | 1 17 21·73 |
| Cephei 51 (Hev.) | 6 47 16·48 | 6 47 16·60 | 6 47 16·57 | 6 47 16·96 |
| δ Ursæ Minoris | 18 8 45·86 | 18 8 46·00 | 18 8 46·00 | 18 8 45·98 |
| λ Ursæ Minoris | 19 36 47·82 | 19 36 46·88 | 19 36 47·72 | 19 36 48·00 |

*Radcliffe Observatory, Oxford:*
1887, *January* 13.

## *Note on the Application of Photography to the Determination of Stellar Parallax.* By the Rev. Prof. Pritchard, D.D., F.R.S.

At the meeting of the Society in June last, I communicated the results of some preliminary trials with the view of ascertaining the applicability of photography to astronomical measurements of sufficient delicacy for the accurate determination of stellar parallax.

These results proving eminently satisfactory, the requisite operations for the determination of parallax commenced on May 26 of last year by taking photographs of the district round $61^1$ and $61^2$ *Cygni*, which star was selected on account of the unusually numerous examinations which had been applied to it by successive astronomers from the time of Bessel (1840) to the present date; my object being not so much to effect a re-determination of the parallax of this historical star as to obtain the means of comparing the photographic method with those other methods of micrometrical measurement heretofore directly applied to this end.

For the purpose in view, four faint stars, viz.:

D.M. + 37° No. 4189 . . . . (*a*)
D.M. + 38 „ 4336 . . . . (*b*)
D.M. + 37 „ 4175 . . . . (*c*)
D.M. + 38 „ 4348 . . . . (*d*)

were selected from others whose images were impressed on the photographic plates. The distances of each of these four stars (eight in all) were carefully measured from each of the two components of 61 *Cygni*, on plates taken on fifty nights, ending on Dec. 7, 1886. In general, four plates were exposed each night, so that some 200 plates have been measured in the course

of the investigation. All these measures were strictly independent of each other, as were also the ultimate reductions. The astronomical importance and novelty of the inquiry seem to me to justify all this expenditure of time and labour.

In order to meet the ever-varying conditions of the instrument in respect of focus, and other contingent elements, the above measures were not reduced in terms of the registered scale of the macro-micrometer; but they were always referred to the presumably constant distance of the star (*a*) from the star (*b*), or of (*c*) from (*d*). These fundamental distances were always measured at the same time as were the other eight.

The proper motion of 61 *Cygni* has been so exactly determined that its effects could be definitively removed from the measured distances, and a temporary solution of the equations on this hypothesis appeared to be desirable and legitimate. The results of this preliminary solution are given as follows:—

| | Star's Designation. | Parallax of $61^1$ Cygni. | Probable Error. | Parallax of $61^2$ Cygni. | Probable Error. |
|---|---|---|---|---|---|
| *a* | D.M. + 37 No. 4189 | 0·4412 | 0·0154 | 0·4204 | 0·0229 |
| *b* | D.M. + 38 „ 4336 | ·4529 | ·0330 | ·4139 | ·0185 |
| *c* | D.M. + 37 „ 4175 | ·4433 | ·0197 | ·4721 | ·0215 |
| *d* | D.M. + 38 „ 4348 | ·4158 | ·0161 | ·4574 | ·0252 |

The provisional *means* for parallaxes thus obtained for the four independent sets of measures of $61^1$ and $61^2$ *Cygni* respectively are as follows: —

**For $61^1$ Cygni . . . . Parallax = $0''{\cdot}438$**

**$61^2$ Cygni . . . . Parallax = $0{\cdot}441$**

Values of the parallax of 61 *Cygni* have been determined by several astronomers; among them are found

Bessel $0''{\cdot}348$ in 1840

Auwers 0·564 in 1863

Ball 0·468 in 1878

Asaph Hall 0·261 in 1880

The Oxford determination is to be regarded as provisional only; the research will be continued to the end of the annual cycle, and full details will be communicated at the earliest opportunity.

In the communication made to the Society in June last reference was made to the liability of the photographic film to be occasionally dislocated. The possibility of such an occurrence renders it advisable in all cases where reliable accuracy is sought to take photographs in duplicate at least. One of the causes of this liability has been traced to its origin in the mechanical

action of the *impact* of water on the film; which *impact* has been regarded as essential to the proper washing of the plate. I find that in the entire series of about 200 plates, seven have exhibited minute but noticeable traces of this dislocation; these have been rejected in the above investigation.

*University Observatory, Oxford:*
*Jan.* 13, 1887.

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## *Photographs of Nebulæ in Orion and in the Pleiades.* By Isaac Roberts.

The accompanying photograph of nebulæ in *Orion* is enlarged five times from a negative which I took on November 30 last, between $4^h\ 13^m$ and $5^h\ 20^m$ sidereal time at Maghull. The exposure was intended to extend to two hours, but an accident stopped it after $1^h\ 7^m$, and clouds have prevented another photograph being taken since that date.

The photographic extensions of the nebulæ may be judged by comparing this photograph with that taken by Mr. Common, and referring to the included and surrounding stars in them respectively, as places from which to measure.

It will thus be seen that the dark space shown on Mr. Common's photograph between the small nebula (Herschel, No. 1185) and the Great Nebula, as well as the "fish mouth," are filled with dense nebulous matter, which also can clearly be traced between Declination $-5°\ 15'$ and $-6°\ 15'$. In Right Ascension it can be traced between $5^h\ 26^m$ and $5^h\ 29^m$—an area about seven times that covered by Mr. Common's photograph.

There is a large, dense, and characteristically marked nebula to the north (Herschel, No. 1180), and the photograph indicates very faint nebulosity stretching some distance between this and the Great Nebula, but hitherto, owing to continuous bad weather, there has been no opportunity for proving by a long exposure of plates that this nebula also forms a part of the Great Nebula. If this should be proved, and there is now reasonable ground for inference, then extensions of the nebula will be revealed to us on a scale still more vast than has hitherto been known.

In the accompanying print the central parts of the nebulæ are white, without any shading, but on the negatives, when they are examined by the eye or under a microscope, those parts are full of detail, and delicate, but dense, cloud-like, curdling masses. I hope that, some time before the close of this session, I may have clear sky to enable me to present to the Society photographic analyses of this nebula, which will show the appearances presented by it with different lengths of exposure.

This method will give a more accurate insight into its constitution, and will furnish more reliable means for detecting any

changes that may take place within it in future, than if I were to draw out the details in a print from one dense negative. I already have some of the negatives which will be required in the demonstrations here proposed.*

## Nebulæ in the Pleiades.

The accompanying photograph was taken on December 29 (last month), between sidereal time at Maghull 2h 55m and 6h 1m. The actual time of the exposure of the plate was three hours.

In bringing before the Society the first and second of the series of photographs of these nebulæ, I stated that upon one of them there were traces of nebulosity which indicated that the principal stars in the *Pleiades* are involved, or are in alignment with one vast nebula, and this photograph seems to prove the correctness of the inference.

The nebula (I now venture to use the singular) is traceable from the north of *Asterope*, and extends southwards 1° 10′. It includes *Taygeta*, *Maia*, *Celæno*, *Electra*, *Alcyone*, *Merope*, and numerous other small stars within itself.

On the north side of *Alcyone* is a dense mass of light, with a dark space between it and the star. The negative shows that it is not due to the contiguous blister on the glass plate. The nebulosity round *Maia* is characterised by broad streamers stretching in northerly and southerly directions: whilst round *Merope* somewhat similar streamers have n.p. to s.f. directions.

From *Electra* stretches a pointed streamer, which can be traced as far as a line drawn from *Maia* to *Merope*, and a little distance further south is another streamer resembling a detached nebulous straight line. These, and many other points, will be clearly seen on examination of the photograph, but much more clearly are they shown on the negatives. These appearances are both new and unexpected, and it is essential that the evidence of their reality should be so clear that it cannot reasonably be doubted. To this end I have taken already six photographs on different dates. The first was on October 23, 1886, with an exposure of $1^h\ 29^m$, and that showed all the features which are indicated on the chart prepared by MM. Henry at the Paris Observatory, and, in addition, large extensions of nebulous matter round *Maia* and *Merope*.

The second photograph was taken on the following night, October 24, with an exposure of three hours, and it showed vast extensions of nebulous matter round, between, and beyond *Alcyone*, *Merope*, *Electra*, *Maia*, *Taygeta*, *Asterope*, and other smaller stars.

These photographs were presented to the Society in November. On October 25, and December 16 and 24, I obtained one negative each night, but the sky was more or less misty, and at

* The short lines upon the photograph were caused by an accidental momentary movement of the instrument during the exposure of the plate.

times cloudy, during the exposure on each occasion, and consequently the nebulæ are not well developed, but what is shown confirms the features on the other negatives.

On December 29 I obtained the sixth negative, an enlargement of which I now present to the Society, and have already given in these notes a brief description of its general appearance.

The photographs are placed in the Library.

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## *A New Variable Star in Puppis.* By A. Stanley Williams.

The variability of the star L. 3105 in *Puppis* does not seem to have attracted attention hitherto. Whilst in southern latitudes last winter, I paid considerable attention to the magnitudes of the stars, and on February 17, 1886, noticed it as being exactly equal in brightness to the neighbouring star L. 3069. Upon referring to some previous determinations of magnitude I found that it had been rated both brighter and fainter than this star, and as these two stars had always been observed for magnitude at the same time, there seemed to be a reasonable suspicion that one or other of them was variable, and they were consequently kept under examination. Further observations soon showed that this suspicion was correct, and that L. 3105 is the variable star. The following table gives all the determinations of magnitude of these two stars which I was able to obtain.

| Date. 1885. | Estimated Mags. L. 3069. | L. 3105. | Remarks. |
|---|---|---|---|
| Nov. 14 | 5·05 | 5·4 | |
| 21 | 4·7 | 4·4 | |
| 1886. Feb. 12 | 4·7 | 4·55 | L. 3105 distinctly a little brighter than L. 3069. |
| 17 | 4·5 | 4·5 | The two stars exactly equal. |
| 21 | 4·7 | 4·7 | Equal. |
| Mar. 16 | 4·7 | 4·9 | L. 3069 distinctly a little brighter than L. 3105. |
| 21 | 4·8 | 5·2 | L. 3069 *distinctly* and *considerably* brighter than L. 3105. |
| 22 | 4·9 | 4·7 | L. 3105 distinctly brighter than L. 3069. |
| 30 | 5·2 | 5·4 | The relative brightness probably more exactly estimated than the actual determinations of brightness, the stars being very low. Two or three days previous L. 3069 was seen distinctly superior to L. 3105, but the date was not registered. |

The results are clearly not sufficiently numerous to indicate in a satisfactory manner the period of variation. This, however, is probably short, and if the differences between the brightness of the two stars L. 3069 and L. 3105 are chiefly considered, the observations are all well represented by a period of about 4·2 days; the probable extent of the variation being about ·7 of a magnitude. The star L. 3105 must have been near a maximum on November 21, 1885, and again on March 22, 1886, but not so near; and near a minimum on March 21, 1886.

The colour of the new variable was noted as "orange yellow" on February 12, 1886. The magnitudes both of this and L. 3069 are given as 5·0 in the *Uranometria Argentina*; Lacaille made them 6 mag., and in the Brisbane Catalogue they are also put at this figure. Behrmann's estimations are $5\frac{1}{3}$ mag. for L. 3069, and 5 mag. for L. 3105. The estimations of brightness given above were made by means of an opera-glass accurately focussed; the comparison stars were as under, the magnitudes being assumed from the "Harvard Photometry":—

| | | | |
|---|---|---|---|
| ι | Canis Majoris | =4·5 | mag. |
| μ | " " | =5·2 | " |
| 17 | " " | =5·9 | " |
| HP. 1342 | " " | =6·1 | " |

The position of L. 3105 for 1887·0 is R.A. $7^h\ 55^m\ 0^s$, Dec. S. 48° 55′·4.

*West Brighton: Dec.* 28, 1886.

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## *On the Variability of the Spectrum of γ Cassiopeiæ.* By Ralph Copeland, Ph.D.

On page 16 of the current volume of the *Monthly Notices*, Mr. O. T. Sherman quotes a passage from Miss Clerke's "History of Astronomy during the Nineteenth Century," which says that the brilliant rays indicative of hydrogen in the spectrum of γ *Cassiopeiæ* died out during the nine years, 1874–1883. As to the fading of the rays there is room for little doubt, but the epochs of their disappearance and reappearance seem unfortunately quite indeterminate. Possibly the lines appear and vanish at comparatively short intervals, for there are two records of their having been seen here nearly in the middle of the nine years mentioned above. The most precise observation was made on Dec. 20, 1879, when testing a large experimental spectroscope which separated the D lines in the Moon's spectrum, and also showed four lines in that of the Great Nebula in *Orion* on the same night. The bright C line was then noted as "superbly

visible" by Lord Crawford (then Lord Lindsay), Mr. J. G. Lohse, and the writer. There is also a record of *two* bright lines having been seen by me on October 28, 1877, one of which was "well seen" about the place of F, the other being referred to about $477^{mmm}$ of wave-length, and described as "another bright line" without further remark. No mention is made of C on this occasion. At present, however, January 11, 1887, C is extremely bright; and as it was not visible at Bothkamp on June 18, 1872, although the red end of the spectrum was specially examined and the position of the bright F determined, there cannot be the slightest doubt as to the variability of the spectrum, as pointed out by M. von Gothard several years ago.

It is very remarkable that the C line is obviously more variable than F* in the spectrum of this most interesting star; this must necessarily involve a certain amount of colour change, which may partly explain the very conflicting evidence respecting the star's variability.

*Lord Crawford's Observatory,*
*Dun Echt: Jan.* 12, 1887.

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*Spectroscopic Observations of the Motion of Stars in the Line of Sight, made at the Temple Observatory, Rugby.* By Geo. M. Seabroke.

In the year 1879 I brought before the notice of the Society some, perhaps rather premature, results of my spectroscopic observations of the motions of stars towards or away from our system. Since that time I have been engaged, whenever a sufficiently long period without interruption could be obtained, in continuing this line of research.

A large number of my observations have been made with a view to perfecting instrumental arrangements, and being, of course, otherwise valueless, are not recorded.

The following arrangement appears at present to be satisfactory, and with it the results detailed below have been obtained.

The telescope is a silver-on-glass Newtonian Reflector of $12\frac{1}{8}$ inches aperture, and 6 feet 6 inches in focal length, equatorially mounted. The spectroscope has a collimator of a focal length of 12 inches and $\frac{3}{4}$-inch aperture, and a Barlow lens in the telescope elongates the cone of rays to fit the same; a cylindrical lens is also used to give sufficient width of spectrum. The prisms are used twice, the rays of light passing first through the lower portions, and back through the upper portions to the observing

* The variability of the F-line was, however, remarked at Greenwich, on September 4, 1884, and may be generally inferred from its varying appearance on several other occasions.

telescope of 1 foot focal length, carrying an eyepiece which magnifies the slit about 15 times. The number of prisms used is equivalent to either 3 or 5 of 60°.

For comparison of the positions of the lines observed, I use a spot of light, or "ghost," produced by the reflection from the surface of the last prism of the rays of light proceeding from a minute slit carried by a micrometer, after passing through a collimating lens. The slit in question is illuminated by rays from a lamp carried on the large telescope, reflected from a silvered glass attached to the micrometer; the light is passed through a glass of a colour as near as possible that of the part of the spectrum under examination, so as to avoid want of focal coincidence.

The vacuum tube, or magnesium wire, is carried in front of the slit, and can be moved to and from that position at pleasure.

To compare the lines, the slit of the spectroscope is illuminated by the star and comparison lights alternately, and a reading of position of each taken with the ghost. The value of the divisions of the micrometer screw are ascertained by measurement of known lines on the solar spectrum.

For these observations the telescope at my disposal is very small, and therefore it is only the spectrum of the brighter stars that I am able to attack. There is a fine field in this line of research open to the possessors of large telescopes giving good definition.

In the following list of measures the sign + means that the star is receding from, and − approaching, our system. The corrected motion is the apparent value corrected for the orbital motion of the earth.

| Number of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *α Andromedæ.* | | |
| 5 | F | 6 | −22·5 | 85·87 | |
| 5 | F | 4 | −29·2 | ·90 | |
| | | | *γ Pegasi.* | | |
| 5 | F | 5 | +13·6 | 85·87 | Very difficult. |
| 5 | F | 4 | −66·8 | ·90 | |
| | | | *α Aurigæ.* | | |
| 5 | F | 2 | −41·5 | 86·27 | Doubtful. |
| 5 | F | 5 | +15·1 | ·32 | |
| 5 | F | 3 | + 8·0 | ·33 | |
| 5 | F | 3 | + 8·5 | ·34 | |
| | | | *γ Geminorum.* | | |
| 5 | F | 3 | −46·3 | 85·19 | |

| Number of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *Sirius.* | | |
| 5 | F | 4 | −31·72 | 86·12 | |
| 5 | F | 9 | −43·6 | ·16 | |
| 5 | F | 7 | −49·5 | ·17 | |
| | | | *Castor.* | | |
| 7 | F | 3 | +19·6 | 82·30 | |
| | | | *Procyon.* | | |
| 7 | F | 5 | +15·8 | 85·19 | |
| 5 | F | 6 | + 7·5 | 86·17 | |
| | | | *Pollux.* | | |
| 7 | F | 2 | −34·4 | | |
| | | | *α Leonis.* | | |
| 7 | F | 5 | +32·1 | 82·30 | |
| 7 | F | 3 | +34·0 | ·35 | |
| 5 | F | 4 | − 0·1 | 85·35 | |
| 5 | F | 3 | − 3·5 | 86·33 | |
| 5 | F | 4 | +52·5 | ·40 | |
| | | | *γ Leonis.* | | |
| 5 | F | 2 | +12·2 | 79·33 | |
| 7 | F | 3 | +23·2 | 82·35 | |
| 7 | F | 2 | −48·5 | ·36 | |
| 5 | F | 4 | + 7·2 | 85·35 | |
| 5 | F | 2 | +21·3 | ·41 | |
| 5 | F | 2 | −31·5 | 86·34 | |
| 5 | F | 2 | −31·5 | ·40 | |
| | | | *α Ursæ Maj.* | | |
| 5 | F | 3 | − 0·5 | 85·42 | |
| 5 | F | 4 | −11·2 | 86·42 | |
| 5 | F | 2 | +22 | ·49 | |
| 5 | F | 3 | +21·5 | ·54 | |
| | | | *γ Ursæ Maj.* | | |
| 5 | F | 3 | −24·9 | 85·42 | |
| 5 | F | 4 | − 6·5 | 86·40 | |
| 5 | F | 4 | −24·9 | ·49 | |

| Number of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *β Ursæ Maj.* | | |
| 5 | F | 5 | −58·7 | 85·42 | |
| 5 | F | 3 | +11·6 | 86·49 | |
| 5 | F | 3 | −50·0 | ·49 | Very doubtful. |
| 5 | F | 4 | +27·2 | ·54 | Line wide. |
| | | | *δ Leonis.* | | |
| 7 | F | 5 | −42·4 | 82·36 | |
| 7 | F | 5 | +39·0 | ·36 | |
| 5 | F | 7 | −44·5 | 85·35 | |
| 5 | F | 4 | −47·0 | ·41 | |
| 5 | F | 3 | +32·0 | 86·40 | |
| 5 | F | 4 | + 7·0 | ·40 | |
| | | | *θ Leonis.* | | |
| 7 | F | 4 | +21·5 | 82·36 | |
| 7 | F | 8 | +33·8 | ·36 | |
| 5 | F | 4 | + 8·2 | 85·35 | |
| 5 | F | 5 | +43·3 | ·41 | |
| 5 | F | 4 | +32·5 | 86·40 | |
| 5 | F | 4 | −31·5 | ·40 | |
| | | | *β Leonis.* | | |
| 5 | F | 4 | +14·5 | 85·35 | |
| 5 | F | 5 | +23·8 | ·41 | |
| 5 | F | 4 | −53·0 | 86·34 | |
| 5 | F | 3 | + 5·0 | ·40 | |
| 5 | F | 3 | −24·5 | ·40 | |
| | | | *δ Ursæ Maj.* | | |
| 5 | F | 3 | −31·6 | 85·42 | |
| 5 | F | 2 | −16·4 | ·48 | |
| 5 | F | 3 | +20·4 | 86·49 | |
| 5 | F | 1 | +36·0 | ·54 | |
| | | | *ζ Virginis.* | | |
| 5 | F | 1 | −43·0 | 85·41 | Doubtful. |
| | | | *ε Ursæ Maj.* | | |
| 5 | F | 3 | −29·3 | 85·41 | |
| 5 | F | 6 | −61·3 | ·48 | |
| 5 | F | 9 | −52·2 | 86·49 | |
| 5 | F | 6 | −69·9 | ·50 | |

| Number of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *ζ Ursæ Maj.* | | |
| 5 | F | 3 | −23·5 | 85·41 | |
| 5 | F | 3 | −48·0 | ·45 | |
| 5 | F | 5 | +20·1 | ·48 | |
| 5 | F | 4 | +14·4 | 86·50 | |
| 5 | F | 4 | − 2·6 | ·54 | |
| 5 | F | 3 | −10·4 | ·64 | |
| 5 | F | 3 | +29·5 | ·66 | |
| 5 | F | 5 | +25·0 | ·69 | |
| 5 | F | 2 | +15·5 | ·70 | |
| | | | *α Virginis.* | | |
| 7 | F | 7 | +16·9 | 82·36 | Difficult. |
| 7 | F | 7 | +13·5 | ·36 | |
| 5 | F | 7 | + 3·7 | 85·41 | |
| 5 | F | 4 | +43·2 | ·41 | |
| | | | *η Bootis.* | | |
| 7 | F | 6 | + 5·9 | 82·37 | |
| 5 | F | 3 | −40·1 | 86·50 | |
| 5 | F | 5 | − 8·5 | ·54 | |
| | | | *η Ursæ Maj.* | | |
| 5 | F | 5 | +25·0 | 86·50 | |
| 5 | F | 5 | −11·1 | ·54 | |
| 5 | F | 5 | +10·0 | ·64 | |
| 5 | F | 4 | + 8·6 | ·66 | |
| 5 | F | 7 | +26·5 | ·69 | |
| 5 | F | 3 | +24·0 | ·70 | |
| 5 | F | 3 | +18·9 | ·70 | |
| | | | *Arcturus.* | | |
| 7 | F | 4 | +24·1 | 82·37 | |
| 5 | F | 5 | +13·2 | 85·41 | |
| 5 | F | 3 | −76·6 | ·44 | |
| 5 | F | 5 | −24·1 | ·45 | |
| 5 | F | 3 | −44·1 | ·48 | |
| 5 | F | 4 | −18·2 | ·48 | |
| 5 | F | 3 | +14·6 | ·51 | |
| 5 | F | 4 | −40·1 | ·55 | |

| Number of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *Arcturus.* | | |
| 5 | F | 3 | + 3·0 | 86·49 | |
| 5 | F | 4 | −43·0 | ·64 | |
| 5 | F | 3 | −29·0 | ·66 | |
| 5 | F | 2 | −36·0 | ·69 | |
| | | | *ε Bootis.* | | |
| 5 | F | 4 | −16·7 | 85·55 | |
| 5 | F | 3 | −29·3 | 86·50 | |
| 5 | F | 1 | + 8·0 | ·66 | |
| 5 | F | 3 | + 2·0 | ·69 | |
| 5 | F | 4 | −36·4 | ·74 | |
| | | | *α Coronæ Bor.* | | |
| 5 | F | 3 | −36·5 | 86·64 | |
| 5 | F | 3 | +13·9 | ·64 | |
| 5 | F | 1 | −33·0 | ·66 | |
| 5 | F | 3 | −45·0 | ·69 | |
| 5 | F | 4 | −27·5 | ·70 | |
| | | | *α Ophiuchi.* | | |
| 5 | F | 4 | −21·3 | 85·51 | |
| 5 | F | 4 | −55·4 | ·75 | |
| 5 | F | 5 | − 1·4 | 86·64 | |
| 5 | F | 4 | −23·1 | ·66 | |
| 5 | F | 2 | + 7·0 | ·69 | |
| 5 | F | 2 | −24·5 | ·69 | |
| | | | *Vega.* | | |
| 7 | F | 3 | −65 | 81·53 | |
| 7 | F | 3 | −45·9 | ·73 | |
| 5 | F | 2 | −28·9 | 85·48 | |
| 5 | F | 4 | −59·2 | ·50 | |
| 5 | F | 8 | −43·3 | ·71 | |
| 5 | F | 3 | −49·2 | ·74 | |
| 5 | F | 2 | −41·5 | 86·69 | |
| 5 | F | 3 | −32·4 | ·70 | |
| 5 | F | 4 | −32·9 | ·72 | |

| umber of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *γ Lyræ.* | | |
| 5 | F | 4 | +11·5 | 86·74 | Very faint. |
| 3 | F | 6 | −44·6 | ·75 | |
| 3 | F | 4 | −35·7 | ·87 | |
| 3 | F | 2 | −66·0 | ·88 | |
| | | | *ζ Aquilæ.* | | |
| 5 | F | 10 | −29·5 | 85·75 | |
| 5 | F | 4 | −177·3 | ·78 | |
| 5 | F | 5 | −30·0 | 86·72 | |
| 3 | F | 5 | +14·0 | ·75 | |
| | | | *γ Aquilæ.* | | |
| 5 | F | | −31·9 | 86·72 | |
| 3 | F | | +34·4 | ·75 | |
| 3 | F | est. | −30·0 | ·87 | |
| | | | *δ Cygni.* | | |
| 7 | F | 2 | −26·5 | 81·74 | |
| 7 | F | 3 | −55·6 | ·79 | |
| 5 | F | 6 | +24·6 | 85·72 | |
| 5 | F | 4 | − 5·8 | ·75 | |
| 5 | F | 4 | −15·7 | ·75 | |
| 5 | F | 4 | +38·1 | ·78 | |
| 5 | F | 2 | −36·9 | ·87 | |
| 3 | F | 5 | −63·5 | 86·80 | |
| 3 | F | 4 | −50·7 | ·88 | |
| 3 | F | 3 | −50·2 | ·91 | |
| | | | *Altair.* | | |
| 5 | F | 3 | +22·7 | 84·70 | |
| 5 | F | 4 | −38·6 | ·77 | |
| 5 | F | 2 | −43·6 | 85·74 | |
| 5 | F | 4 | + 6·0 | ·75 | |
| 5 | F | 7 | −19·4 | ·75 | |
| 5 | F | 5 | −25·1 | ·78 | |
| 5 | F | 3 | −22·0 | 86·64 | |
| 5 | F | 7 | − 0·4 | ·72 | |
| 5 | F | 4 | − 2·8 | ·74 | |
| 3 | F | 4 | −70·0 | ·88 | |

| Number of Prisms. | Line Compared. | Number of Measures. | Cor. Motion in Miles per Second. | Date 1800+ | Remarks. |
|---|---|---|---|---|---|
| | | | *γ Cygni.* | | |
| 7 | F | 5 | −68·0 | 81·79 | |
| 5 | F | 4 | −46·3 | 85·75 | |
| 5 | F | 5 | +33·2 | ·90 | |
| 3 | F | 4 | −57·0 | 86·80 | |
| 3 | F | 3 | −57·5 | ·88 | |
| 3 | F | 3 | −66·0 | ·91 | |
| | | | *α Cygni.* | | |
| 7 | F | 2 | +31·0 | 81·73 | |
| 7 | F | 3 | −32·8 | ·78 | |
| 7 | F | 3 | +29·9 | ·79 | |
| 7 | F | 7 | −35·5 | ·79 | |
| 5 | F | 6 | −22·5 | 86·69 | |
| 5 | F | 3 | +18·5 | ·69 | |
| 3 | F | 5 | −34·0 | ·80 | |
| 3 | F | 5 | −18·6 | ·91 | |
| | | | *ε Cygni.* | | |
| 7 | F | 2 | −53·4 | 81·79 | Uncertain. |
| 5 | F | 4 | −21·7 | 85·87 | |
| 3 | F | 2 | −63·0 | 86·80 | |
| 3 | F | 1 | −59·0 | ·91 | |
| | | | *η Pegasi.* | | |
| 5 | F | 4 | −54·4 | 85·8 | |
| | | | *α Pegasi.* | | |
| 6 | F | 4 | − 0·2 | 80·88 | |
| 7 | F | 2 | −39·5 | 81·79 | |
| 5 | F | 4 | −44·6 | 85·87 | |
| 5 | F | 6 | −41·6 | ·87 | |
| 5 | F | 5 | −21·9 | ·90 | |
| | | | *β Pegasi.* | | |
| 5 | F | 1 | + 1·8 | 85·87 | |

## *Spectroscopic Results for the Motions of Stars in the Line of Sight, obtained at the Royal Observatory, Greenwich, in the year 1886.* No. X.

(*Communicated by the Astronomer Royal.*)

The results here given are in continuation of those printed in the *Monthly Notices*, vol. xxxvi. p. 318, vol. xxxvii. p. 22, vol. xxxviii. p. 493, vol. xli. p. 109, vol. xlii. p. 230, vol. xliii. p. 81, vol. xliv. p. 89, vol. xlv. p. 330, and vol. xlvi. p. 126. The observations were made with the "half-prism" spectroscope, one "half-prism" with a dispersion of about $18\frac{1}{2}°$ from A to H being used throughout. Eyepieces with magnifying powers of 14 and 22 respectively were employed.

The cylindrical lens has always been used in front of the slit as in the observations made previously to 1881. The observations of the Moon and of the sky have been made as a check on the general accuracy of the results.

The day specified in the first column is the Civil Day, and the hour is that of Greenwich Civil Time, commencing at Greenwich Mean Midnight, and reckoning from 0 to 24 hours.

*Motions of Stars in the Line of Sight, in Miles per Second, observed with the Half-prism Spectroscope.*

(+ denotes Recession; − Approach.)

The initials M., N., and L. are those of Mr. Maunder, Mr. Nash, and Mr. Lewis respectively.

| Date. 1886. | | h | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *α Andromedæ.* | | | |
| Jan. | 27 | 19 | M | 2 | F | +15·4 | −26·4 | −23·6 | Spectrum fairly steady. |
| Feb. | 1 | 19 | M | 2 | F | +14·7 | −75·3 | −44·2 | Definition poor. |
| Nov. | 5 | 23 | M | 2 | F | + 8·6 | (− 2·0) | (+ 2·5) | Spectroscope out of adjustment. |
| | | | | | | *γ Pegasi.* | | | |
| Feb. | 1 | 19 | M | 2 | F | +15·0 | − 6·5 | − 5·7 | Definition bad; star-line seen with great difficulty. |
| | | | | | | *β Arietis.* | | | |
| Feb. | 1 | 19 | M | 2 | F | +18·4 | −85·4 | −45·5 | Definition very bad. |
| Dec. | 4 | 21 | M | 4 | F | +12·1 | +12·4 | +11·8 | Definition good. |
| | | | | | | *β Persei.* | | | |
| Jan. | 27 | 20 | M | 2 | F | +16·8 | −50·2 | −46·4 | Definition fair. |
| Feb. | 1 | 20 | M | 2 | F | +17·1 | −28·6 | −30·7 | Wind high but definition fair. |

| Date. 1886. | h | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | | | | | *β Persei.* | | |
| Nov. 29 | 20 | M | 6 | F | + 3·9 | + 4·3 | + 2·1 | Definition good. |
| Dec. 4 | 22 | M | 4 | F | + 5·4 | −111·8 | −106·4 | Spectrum faint; definition poor. |
| 14 | 20 | M | 5 | F | + 8·3 | +12·2 | +13·6 | Definition fair. |
| 14 | 20 | L | 5 | F | + 8·3 | − 3·4 | +12·1 | Definition fair. |
| | | | | | | *α Persei.* | | |
| Jan. 27 | 20 | M | 2 | F | +15·1 | −40·9 | −34·8 | Definition fair. |
| Feb. 1 | 20 | M | 2 | F | +15·6 | −21·2 | −25·7 | Wind very high; definition poor. |
| Nov. 29 | 21 | M | 2 | F | + 2·0 | + 6·8 | + 7·6 | Star-line faint. |
| Dec. 4 | 23 | M | 2 | F | + 3·5 | −10·4 | − 7·6 | Definition good. |
| | | | | | | *Aldebaran.* | | |
| Jan. 27 | 20 | M | 2 | F | +16·3 | +22·9 | + 8·3 | |
| Mar. 3 | 21 | M | 2 | F | +18·5 | +24·8 | +13·4 | Definition poor. |
| 17 | 20 | M | 2 | $b_1$ | +17·4 | +13·6 | +24·9 | Definition poor. |
| Nov. 17 | 23 | M | 4 | F | − 4·1 | +44·3 | +40·0 | Star-line faint. |
| 29 | 22 | M | 2 | F | − 0·2 | +18·9 | +18·2 | Definition poor. |
| Dec. 4 | 23 | M | 2 | F | + 1·5 | +41·5 | +43·0 | Definition fair. |
| | | | | | | *Capella.* | | |
| Jan. 27 | 22 | M | 4 | F | +12·9 | − 4·0 | − 3·9 | Star-line very well seen. |
| Mar. 3 | 21 | M | 2 | F | +17·1 | −54·5 | −52·5 | Definition fair. |
| 17 | 20 | M | 2 | $b_1$ | +16·9 | +42·3 | +46·6 | Star-line faint. |
| 23 | 21 | N | 2 | $b_1$ | +16·6 | −20·8 | −16·6 | Spectrum tremulous; star-line faint. |
| Apr. 6 | 22 | N | 2 | F | +15·1 | + 1·5 | − 0·4 | Spectrum tremulous. |
| Nov. 29 | 22 | M | 2 | F | − 3·8 | +29·5 | +30·2 | Star-line faint. |
| | | | | | | *Rigel.* | | |
| Jan. 27 | 21 | M | 2 | F | +12·9 | +30·6 | +17·8 | Star-line fairly well seen. |
| Feb. 1 | 20 | M | 2 | F | +13·7 | + 5·5 | + 0·3 | Wind *very* high; star-line seen with great difficulty. |
| Mar. 3 | 20 | M | 2 | F | +16·0 | +19·4 | + 8·8 | Definition poor; measures rough. |
| Nov. 5 | 23 | M | 2 | F | − 8·4 | (+58·5) | (+61·6) | Spectroscope out of adjustment. |
| 18 | 0 | M | 2 | F | − 5·4 | + 9·8 | + 9·6 | Star-line distinct and well-defined. |
| | | | | | | *γ Orionis.* | | |
| Jan. 27 | 21 | M | 2 | F | +13·6 | + 4·9 | − 2·7 | Star-line very well seen. |
| Feb. 1 | 20 | M | 2 | F | +14·6 | − 1·3 | − 4·0 | Wind very high; star-line seen with great difficulty. |

| Date. 1886. | | | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *γ Orionis.* | | | |
| | | h | | | | | | | |
| Mar. | 3 | 20 | M | 2 | F | +17·8 | + 6·3 | + 0·6 | Star-line seen with great difficulty. |
| Nov. | 18 | 1 | M | 4 | F | − 7·2 | +11·5 | +11·6 | Spectrum fairly bright and steady. |
| | | | | | | *β Tauri.* | | | |
| Jan. | 27 | 21 | M | 2 | F | +13·8 | −38·0 | −37·9 | Star-line fairly well seen. |
| Feb. | 1 | 21 | M | 2 | F | +14·8 | −25·4 | −25·3 | Wind very high. Definition bad. |
| Mar. | 3 | 20 | M | 4 | F | +18·4 | −31·5 | −35·1 | Definition poor. |
| Nov. | 18 | 1 | M | 2 | F | − 8·0 | − 8·0 | − 8·1 | Star-line well seen. |
| | | | | | | *δ Orionis.* | | | |
| Jan. | 27 | 21 | M | 2 | F | +12·7 | + 7·8 | + 3·8 | Spectrum rather faint and tremulous. |
| | | | | | | *ε Orionis.* | | | |
| Jan. | 27 | 21 | M | 2 | F | +12·4 | +14·8 | + 7·3 | Spectrum rather faint and tremulous. |
| | | | | | | *ζ Orionis.* | | | |
| Jan. | 27 | 21 | M | 2 | F | +12·1 | +13·2 | +14·2 | Spectrum rather faint and tremulous. |
| | | | | | | *κ Orionis.* | | | |
| Jan. | 27 | 21 | M | 2 | F | +10·9 | −21·4 | −19·1 | Star-line fairly well seen. |
| | | | | | | *α Orionis.* | | | |
| Mar. | 17 | 21 | M | 2 | $b_4$ | +17·8 | +34·0 | +39·4 | Definition fair. |
| | | | | | | *β Aurigæ.* | | | |
| Jan. | 27 | 22 | M | 2 | F | +11·3 | −35·5 | −40·9 | Spectrum rather faint and tremulous. |
| Mar. | 3 | 21 | M | 2 | F | +16·8 | −58·7 | −55·1 | Definition fair. |
| | | | | | | *γ Geminorum.* | | | |
| Jan. | 27 | 22 | M | 6 | F | + 9·5 | −48·1 | −40·7 | Spectrum bright and steady, but star-line exceedingly broad and diffused and difficult to bisect. |
| Feb. | 1 | 21 | M | 2 | F | +10·9 | −43·7 | −34·2 | Wind very high; definition bad. |
| | | | | | | *Sirius.* | | | |
| Jan. | 19 | 22 | M | 2 | F | + 4·4 | −13·7 | −13·1 | Spectrum very tremulous. |
| | 27 | 22 | M | 6 | F | + 6·3 | −32·6 | −32·2 | |
| Mar. | 3 | 22 | M | | F | +12·6 | −38·6 | −35·7 | Definition bad. Star in light cloud. |
| Nov. | 5 | 1 | M | 4 | F | −12·3 | (+31·0) | (+32·3) | Spectroscope out of adjustment. |
| | 18 | 2 | M | 6 | F | −10·6 | + 8·4 | + 8·3 | Star-line well seen. |

| Date. 1886. | | h | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Castor.* | | |
| Jan. | 27 | 23 | M | 2 | F | + 6·2 | +29·2 | +32·1 | Spectrum tremulous; star-line very ill-defined. |
| Apr. | 6 | 23 | N | 4 | F | +18·0 | −14·9 | −15·8 | Star-line ill defined. |
| May | 1 | 22 | M | 2 | F | +16·4 | +24·7 | +13·0 | Definition good. |
| Nov. | 18 | 2 | M | 2 | F | −14·7 | +27·8 | +27·2 | Star-line well seen. |
| | | | | | | | *Procyon.* | | |
| Jan. | 18 | 23 | N | 3 | F | + 1·5 | + 0·3 | − 1·5 | Spectrum bright; definition fair. |
| | 27 | 23 | M | 6 | F | + 4·4 | −13·8 | −13·5 | Spectrum bright; definition good. |
| | 28 | 22 | N | 1 | F | + 4·7 | − 4·1 | − 4·7 | |
| Mar. | 3 | 22 | M | 4 | F | +13·6 | −38·8 | −41·3 | |
| Apr. | 6 | 22 | N | 2 | F | +17·5 | −21·5 | −21·9 | |
| May | 1 | 21 | M | 2 | F | +16·6 | −57·9 | −41·3 | Definition bad; measures very rough. |
| Nov. | 18 | 2 | M | 4 | F | −15·4 | + 9·5 | + 9·8 | Star-line well seen. |
| | | | | | | | *Pollux.* | | |
| Jan. | 27 | 23 | M | 2 | F | + 5·3 | −45·1 | −51·8 | Definition good. |
| Mar. | 17 | 22 | M | 2 | $b_1$ | +16·8 | −29·4 | −39·0 | Star-line difficult to see. |
| | 23 | 23 | N | 2 | $b_1$ | +17·4 | −24·3 | −23·8 | Measures rendered difficult by mist. |
| Apr. | 6 | 23 | N | 2 | F | +18·1 | −30·5 | −29·9 | Spectrum tremulous; star-line faint. |
| May | 1 | 22 | M | 2 | F | +16·9 | −45·8 | −45·1 | Measures made with great difficulty. |
| Nov. | 18 | 2 | M | 2 | F | −15·5 | −15·5 | −12·3 | Star-line fairly well seen at times. |
| | | | | | | | *Regulus.* | | |
| Apr. | 30 | 22 | N | 2 | F | +17·2 | −17·2 | −17·2 | |
| May | 3 | 23 | M | 2 | F | +17·5 | + 1·8 | + 4·7 | Spectrum bright; definition fair. |
| | 6 | 23 | N | 2 | F | +17·6 | −14·3 | −13·4 | Measures made with difficulty. |
| | 15 | 21 | M | 2 | F | +17·9 | − 5·2 | − 3·4 | Star-line very ill-defined. |
| | 18 | 23 | N | 2 | F | +17·9 | − 3·0 | − 2·9 | Star-line diffused and faint. |
| | | | | | | | *β Ursæ Majoris.* | | |
| May | 1 | 23 | M | 2 | F | +12·7 | + 5·7 | − 2·0 | Spectrum faint; measures rough. |
| | | | | | | | *α Ursæ Majoris.* | | |
| May | 1 | 23 | M | 2 | F | +11·7 | −59·7 | −52·7 | Star-line very difficult to see. |
| June | 16 | 1 | N | 2 | $b_1$ | + 8·7 | −57·3 | −57·5 | |

| Date. 1886. | | | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Concluded Motion of Star. Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *δ Leonis.* | | | |
| | | h | | | | | | | |
| May | 15 | 22 | M | 2 | F | +16·8 | −44·0 | −50·1 | Definition fair. |
| | | | | | | *β Leonis.* | | | |
| Apr. | 30 | 23 | N | 2 | F | +13·6 | −30·5 | −30·3 | |
| May | 4 | 1 | M | 2 | F | +14·2 | −10·9 | −10·5 | Spectrum fairly bright and steady. |
| | 15 | 22 | M | 2 | F | +15·9 | −14·7 | −13·8 | Definition fair. |
| | | | | | | *γ Ursæ Majoris.* | | | |
| May | 1 | 23 | M | 2 | F | +11·7 | + 1·2 | + 0·8 | Star-line very ill-defined. |
| June | 16 | 0 | N | 2 | $b_1$ | +10·9 | − 2·9 | − 2·8 | Spectrum faint, but star-line seen well at times. |
| | | | | | | *γ Virginis.* | | | |
| May | 4 | 1 | M | 2 | F | +10·3 | −43·6 | −41·1 | Spectrum fairly bright and steady. |
| | | | | | | *ε Ursæ Majoris.* | | | |
| May | 1 | 23 | M | 2 | F | + 9·5 | − 5·1 | − 3·0 | Star-line very ill-defined. |
| | | | | | | *α Canum Venaticorum.* | | | |
| May | 13 | 22 | M | 2 | F | +11·9 | −35·6 | −36·8 | Spectrum steady, but definition poor. |
| | | | | | | *Spica.* | | | |
| Apr. | 30 | 23 | N | 2 | F | + 5·7 | −16·5 | −15·7 | |
| May | 4 | 1 | M | 2 | F | + 6·6 | −60·8 | −53·4 | Spectrum very tremulous. |
| | 18 | 23 | N | 2 | F | +10·5 | − 7·4 | − 6·4 | Definition poor; measures rough. |
| | | | | | | *ζ Ursæ Majoris.* | | | |
| May | 2 | 0 | M | 2 | F | + 8·4 | + 6·5 | + 7·0 | Definition fair. |
| | | | | | | *Arcturus.* | | | |
| Apr. | 30 | 23 | N | 2 | F | + 4·8 | −21·0 | −21·5 | |
| May | 4 | 2 | M | 2 | F | + 5·5 | −71·3 | −64·6 | Spectrum bright; definition good. |
| | 6 | 23 | N | 2 | F | + 6·2 | −23·7 | −23·9 | |
| | 13 | 22 | M | 2 | F | + 7·8 | −35·0 | −39·4 | Spectrum bright, but definition poor. |
| | 18 | 23 | N | 2 | F | + 8·9 | −35·0 | −33·5 | |
| | 20 | 22 | N | 2 | F | + 9·3 | −26·5 | −27·8 | Star-line very indistinct. |

| Date. 1886. | | | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Arcturus.* | | | |
| | | h | | | | | | | |
| June | 7 | 22 | M | 2 | $b_1$ | +12·5 | −49·1 | −46·9 | Spectrum and star-lines rather faint. |
| | 15 | 23 | N | 2 | $b_1$ | +13·5 | −57·3 | −54·2 | |
| | 28 | 23 | M | 2 | $b_1$ | +14·7 | −37·8 | −38·7 | Definition poor. |
| July | 5 | 23 | M | 2 | F | +15·1 | −36·8 | −38·9 | Star-line seen fairly well at times. |
| | | | | | | *$\epsilon^2$ Bootis.* | | | |
| June | 28 | 23 | M | 2 | F | +12·7 | −15·0 | −10·4 | Definition bad. |
| | | | | | | *β Libræ.* | | | |
| May | 13 | 23 | M | 2 | F | + 1·7 | −24·8 | −23·3 | Spectrum bright, but tremulous. |
| | | | | | | *α Coronæ Borealis.* | | | |
| May | 4 | 2 | M | 4 | F | + 0·7 | −26·6 | −23·8 | Star-line very difficult to bisect. |
| | 14 | 0 | M | 2 | F | + 2·8 | +12·8 | +19·6 | Spectrum bright; definition fair. |
| | 20 | 23 | N | 2 | F | + 4·2 | −16·2 | −15·0 | |
| July | 5 | 23 | M | 2 | F | +11·4 | +24·3 | +24·3 | Definition fair. |
| | | | | | | *α Serpentis.* | | | |
| June | 29 | 0 | M | 2 | $b_1$ | +11·7 | − 4·0 | − 1·5 | Star-lines very faint; definition poor. |
| | | | | | | *β Serpentis.* | | | |
| May | 14 | 0 | M | 2 | F | + 1·3 | −14·2 | −16·2 | Star-line well seen. |
| | | | | | | *γ Herculis.* | | | |
| May | 14 | 1 | M | 1 | F | − 1·1 | −36·9 | −38·8 | Observation interrupted by cloud. |
| | | | | | | *α Ophiuchi.* | | | |
| July | 5 | 23 | M | 2 | F | + 5·7 | −19·7 | −19·6 | Definition fair. |
| | | | | | | *γ Draconis.* | | | |
| June | 29 | 1 | M | 2 | $b_1$ | + 0·9 | +20·9 | +33·7 | Definition bad; star-lines seen with great difficulty. |
| | | | | | | *Vega.* | | | |
| July | 6 | 0 | M | 2 | F | + 0·0 | −12·9 | −11·9 | Definition fair. |
| Aug. | 10 | 23 | N | 2 | F | + 4·8 | −29·7 | −31·3 | Spectrum bright and steady; definition good. |

| Date. 1886. | | h | Obs. | No. of Meas. | Line. | Earth's Motion in miles per sec. | Concluded Motion of Star. Meas. | Estimd. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Vega.* | | | | |
| Oct. | 13 | 20 | M | 2 | F | + 8·7 | −60·8 | −48·6 | Observations interrupted by cloud. |
| | 22 | 19 | M | 2 | F | + 8·5 | −58·6 | −44·8 | Spectrum bright and steady. |
| | | | | | *Altair.* | | | | |
| July | 6 | 1 | M | 2 | F | − 4·3 | −23·7 | −21·5 | Definition fair. |
| Aug. | 10 | 23 | N | 2 | F | + 4·9 | −31·2 | −32·8 | Star-line broad and diffused. |
| Oct. | 18 | 22 | M | 2 | F | +16·1 | −67·6 | −54·4 | Spectrum very faint and tremulous. |
| | 22 | 20 | M | 1 | F | +16·2 | −42·9 | −38·5 | Spectrum bright and fairly steady. |
| | | | | | *γ Cygni.* | | | | |
| June | 29 | 1 | M | 2 | $b_1$ | − 6·9 | + 9·9 | +12·2 | Definition very bad. |
| | | | | | *α Cygni.* | | | | |
| June | 29 | 2 | M | 2 | $b_1$ | − 7·4 | + 0·5 | − 0·6 | Definition bad; star-lines seen with great difficulty. |
| July | 6 | 1 | M | 2 | F | − 6·8 | −22·1 | −23·0 | Definition fair. |
| Oct. | 18 | 22 | M | 2 | F | + 7·3 | −55·3 | −45·6 | Definition fair. |
| | | | | | *α Pegasi.* | | | | |
| Jan. | 27 | 19 | M | 4 | F | +12·4 | −34·4 | −26·1 | Measures made with great difficulty. |
| Feb. | 1 | 19 | M | 2 | F | +11·2 | −35·8 | −25·1 | Definition bad; measures rough. |
| Aug. | 11 | 1 | N | 2 | F | − 9·3 | + 3·4 | + 5·4 | Spectrum faint. |
| | | | | | *Mars.* | | | | |
| Mar. | 17 | 22 | M | 4 | $b_1$ | | +10·8 | +15·9 | Definition fair; calculated motion +2·0. |
| | 23 | 23 | N | 4 | $b_1$ | | − 6·9 | − 9·0 | Planet-line faint; calculated motion +3·3. |
| Apr. | 6 | 23 | N | 2 | F | | + 2·3 | + 1·5 | Calculated motion +5·6. |
| | 22 | 23 | N | 1 | F | | + 1·8 | 0·0 | Calculated motion +7·3. |
| | 30 | 22 | N | 2 | F | | + 5·1 | + 4·0 | Calculated motion +7·8. |
| May | 4 | 0 | M | 4 | F | | − 7·2 | − 7·4 | Definition fair; calculated motion +8·0. |
| | | | | | *Venus.* | | | | |
| Jan. | 16 | 18 | M | 10 | F | | − 6·8 | − 7·7 | Computed motion −6·7. |
| | 27 | 18 | M | 10 | F | | −13·6 | − 7·6 | Computed motion −5·4. |

*Moon.*

| Date. | | Obs. | No. of Meas. | Line. | Motion Measured. | Remarks. |
|---|---|---|---|---|---|---|
| | h | | | | | |
| Jan. 18 | 23 | N | 4 | F | +2·5 | The coincidence of the two spectra appeared perfect. |
| Mar. 17 | 22 | M | 5 | $b_1$ | −0·1 | |
| May 13 | 23 | M | 5 | F | +0·2 | |
| 15 | 23 | M | 5 | F | −1·1 | |
| 18 | 23 | N | 4 | F | −1·5 | |
| 20 | 23 | N | 4 | F | −4·6 | |
| June 15 | 23 | N | 4 | $b_1$ | −5·4 | |
| Aug. 10 | 23 | N | 5 | F | −1·9 | |
| Nov. 5 | 23 | M | 5 | F | (+5·5) | The comparison was not quite satisfactory. |
| 18 | 3 | M | 5 | F | +0·3 | The coincidence of the two spectra appeared perfect. |
| Dec. 4 | 22 | M | 5 | F | +0·9 | |

*Sky.*

| Date. | | Obs. | No. of Meas. | Line. | Motion Measured. | Remarks. |
|---|---|---|---|---|---|---|
| Jan. 28 | 12 | M | 5 | F | +1·2 | The coincidence of the two spectra appeared perfect. |
| Feb. 2 | 12 | M | 5 | F | +3·2 | |
| Mar. 4 | 12 | M | 5 | F | −2·1 | No want of coincidence could be detected. |
| 24 | 12 | N | 3 | F | −2·5 | The coincidence of the two spectra appeared perfect. |
| May 3 | 10 | M | 5 | F | −0·6 | |
| June 8 | 10 | M | 5 | $b_1$ | +4·1 | |
| 29 | 12 | M | 5 | $b_1$ | −0·9 | |
| July 6 | 13 | M | 5 | F | +1·8 | |
| Nov. 30 | 12 | M | 5 | F | −2·0 | No want of coincidence could be detected. |

*Rotation of Jupiter.*

Displacement between the $p$ and $f$ limbs.

| Date. | | Obs. | No. of Meas. | Line. | $p-f$. | Remarks. |
|---|---|---|---|---|---|---|
| May 15 | 23 | M | 5 | F | +32·3 | Position-angle of slit 26°. The mean point observed was about 0″·5 from the limb. Definition fair. |

Computed relative motion of the limbs $p - f$ +30·9 miles per second, the equatorial diameter of *Jupiter* being taken as 88,000 miles, and its period of rotation as $9^h\ 56^m$.

*Occultations of Stars by the Moon.*

| Day of Obs. | | Phenomenon. | | Telescope. | Power. | Moon's Limb. | Mean Solar Time of Observation. h m s | Observer. |
|---|---|---|---|---|---|---|---|---|
| 1886, Jan. | 14 | Disapp. | Bradley 381 | Altaz. | 100 | Dark | 7 8 24·46 | H. |
| | 16 | Reapp. | $\theta^2$ Tauri | E. Eq. | 70 | Bright | 4 56 18·41 | H. |
| | 16 | „ | $\theta^2$ Tauri | Simms' Eq. | 220 | „ | 4 56 17·65 | L. |
| | 16 | „ | $\theta^1$ Tauri | E. Eq. | 70 | „ | 4 57 59·03 | H. |
| | 16 | Disapp. | Bradley 619 | N. Eq. | 80 | Dark | 4 58 15·31 | C. |
| | 16 | „ | Aldebaran | N. Eq. | 80 | „ | 7 47 37·09 | C. |
| | 16 (*a*) | „ | Aldebaran | S.E. Eq. | 220 | „ | 7 47 36·03 | M. |
| | 16 | „ | Aldebaran | Altaz. | 100 | „ | 7 47 37·27 | L. |
| | 16 | „ | Aldebaran | E. Eq. | 70 | „ | 7 47 37·05 | H. |
| | 16 (*b*) | Reapp. | Aldebaran | N. Eq. | 80 | Bright | 8 48 27·45 | C. |
| | 16 (*c*) | „ | Aldebaran | S.E. Eq. | 220 | „ | 8 48 28·07 | M. |
| | 16 (*d*) | „ | Aldebaran | Altaz. | 100 | „ | 8 48 28·23 | L. |
| | 16 (*e*) | „ | Aldebaran | E. Eq. | 70 | „ | 8 48 (31·81) | H. |
| | 18 | Disapp. | 26 Geminorum | E. Eq. | 70 | Dark | 8 37 14·94 | L. |
| | 18 | „ | 26 Geminorum | Altaz. | 100 | „ | 8 37 15·48 | H. |
| Mar. | 9 (*f*) | „ | $\xi^1$ Ceti | Lassell Refl. | 130 | „ | 6 34 24·38 | H. T. |
| | 9 | „ | $\xi^1$ Ceti | Altaz. | 100 | „ | 6 34 23·77 | A. D. |
| | 9 (*g*) | „ | $\xi^1$ Ceti | E. Eq. | 70 | „ | 6 34 24·33 | L. |
| | 9 | Reapp. | Ceti | Simms' Eq. | 80 | Bright | 7 39 27·58 | H. T. |
| | 9 | „ | 64 Ceti | E. Eq. | 70 | „ | 6 38 3·23 | L. |

| Day of Obs. | | Phenomenon. | Telescope. | Power. | Moon's Limb. | Mean Solar Time of Observation. | Observer. |
|---|---|---|---|---|---|---|---|
| | | | | | | h m s | |
| 1886, April 10 | Disapp. | 26 Geminorum | E. Eq. | 210 | Dark | 10 24 13·83 | L. |
| 15 | „ | $\tau$ Leonis | Altaz. | 100 | „ | 9 20 42·17 | H. |
| May 6 | „ | 111 Tauri | Altaz. | 100 | „ | 8 11 2·18 | L. |
| June 23 | Reapp. | 24 Piscium | Altaz. | 100 | „ | 13 48 56·08 | R. |
| Aug. 19 | „ | $\nu$ Piscium | Altaz. | 100 | „ | 11 47 50·56 | R. |
| 19 | „ | $\nu$ Piscium | E. Eq. | 70 | „ | 11 47 51·38 | H. W. |
| Sept. 7 | Disapp. | Brad. 2402 | Altaz. | 100 | „ | 9 43 1·55 | A. D. |
| 7 | „ | Brad. 2402 | E. Eq. | 70 | „ | 9 43 1·77 | H. |
| Oct. 22 | Reapp. | 44 Leonis | E. Eq. | 70 | „ | 14 38 48·50 | H. T. |
| 22 | „ | Piazzi X. 67 | E. Eq. | 70 | „ | 14 49 2·71 | H. T. |
| Nov. 21 (h) | „ | 46 Virginis | Altaz. | 100 | „ | 17 31 21·05 | L. |
| Dec. 3 | Disapp. | $h^1$ Aquarii | Altaz. | 100 | „ | 5 8 28·30 | T. |
| 3 | „ | $h^1$ Aquarii | E. Eq. | 70 | „ | 5 8 28·45 | L. |
| 3 | „ | $h^2$ Aquarii | E. Eq. | 70 | „ | 5 9 28·98 | L. |
| 3 (i) | „ | $h^3$ Aquarii | Lassell Refl. | 170 | „ | 5 29 36 24 | H. T. |
| 10 (j) | „ | Bradley 686 | Altaz. | 100 | „ | 10 28 37·40 | J. P. |
| 18 (k) | Reapp. | $\gamma^1$ Virginis | Altaz. | 100 | „ | 14 34 5·34 | T. |

*Notes.*

(a) Disappearance instantaneous. (b) Reappearance did not seem to be quite instantaneous.

(c) The reappearance occupied a *minute* but perceptible interval, say ·2 of a second or less. The time recorded is that of the commencement of the reappearance. (d) Star seemed to take about half a second to clear the Moon's limb; high wind.

(e) Observation not considered satisfactory, as high wind prevented the clock being heard distinctly.

(f) Star seemed to disappear instantaneously when well within the dark limb.

(g) The star at disappearance seemed to be well within the dark limb; the disappearance was instantaneous. (h) Cloudy.

(i) Star appeared very faint before disappearance. (j) Star faint.

(k) The ...

*Phenomena of Jupiter's Satellites.*

| Day of Obs. | | Satellite. | Phenomenon. | | Telescope. | Power. | Mean Solar Time of Observation. | Mean Solar Time of N.A. | Observer. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | h m s | h m s | |
| 1886, Feb. | 22 (*a*) | I. | Ecl. D. | Began to fade | Altnz. | 100 | 10 13 27 | 10 15 8 | L. |
| | 22 | I. | | Last seen | „ | „ | 10 15 8 | | „ |
| | 23 (*b*) | I. | Tr. Egr. | Last contact | Simms' Eq. | 220 | 10 17 21 | 10 16 | H. T. |
| Mar. | 8 | II. | Ecl. D. | Last seen | E. Eq. | 70 | 12 51 6 | 12 50 30 | H. |
| | 9 | I. | Tr. Ing. | First contact | „ | 210 | 11 29 18 | 11 31 | L. |
| | 9 | I. | | Last contact | „ | 210 | 11 32 22 | | „ |
| | 9 (*c*) | I. | Tr. Egr. | First contact | „ | 70 | 13 41 41 | 13 45 | „ |
| | 9 | I. | | Last contact | „ | „ | 13 45 11 | | „ |
| | 10 | III. | Occ. R. | First seen | Simms' Eq. | 80 | 9 52 22 | 9 58 | H. |
| | 10 (*d*) | III. | | Bisection | „ | „ | 9 56 37 | | „ |
| | 10 | III. | | Last contact | „ | „ | 10 2 17 | | „ |
| | 10 | II. | Tr. Egr. | First contact | E. Eq. | 210 | 10 41 30 | 10 49 | T. |
| | 10 | II. | | Last contact | „ | „ | 10 44 45 | | „ |
| | 10 | I. | Occ. R. | First seen | „ | „ | 10 56 13 | 10 59 | „ |
| | 10 | I. | | Last contact | „ | „ | 10 58 42 | | „ |
| | 11 | I. | Tr. Egr. | First contact | Simms' Eq. | 140 | 8 8 16 | 8 11 | L. |
| | 11 | I. | | Last contact | „ | „ | 8 12 21 | | „ |
| | 11 (*e*) | IV. | Ecl. R. | First seen | „ | 220 | 12 35 35 | 12 28 45 | H. T. |
| | 17 | III. | Ecl. D. | Last seen | „ | „ | 10 8 31 | 10 6 43 | A. D. |
| | 17 (*f*) | II. | Tr. Ing. | First contact | „ | „ | 10 12 31 | 10 16 | „ |
| | 17 | II. | Tr. Ing. | Last contact | „ | „ | 10 19 16 | | „ |

| Day of Obs. | | Satellite. | Phenomenon. | | Telescope. | Power. | Mean Solar Time of Observation. | Mean Solar Time of N.A. | Observer. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | h m s | h m s | |
| 1886, Apr. | 1 (*g*) | I. | Tr. Ing. | Last contact | E. Eq. | 210 | 11 10 28 | 11 9 | H. |
| | 3 | I. | Tr. Egr. | First contact | Altaz. | 100 | 7 45 34 | 7 50 | T. |
| | 3 | I. | | Last contact | ,, | ,, | 7 48 48 | | ,, |
| | 8 | I. | Tr. Ing. | First contact | ,, | ,, | 12 50 39 | 12 54 | ,, |
| | 8 | I. | | Last contact | ,, | ,, | 12 55 9 | | ,, |
| | 9 | I. | Occ. D. | Last seen | ,, | ,, | 10 5 39 | 10 5 | A. P. |
| | 9 | I. | | Last seen | E. Eq. | 210 | 10 5 14 | | S. D. |
| | 9 | II. | | Last seen | Altaz. | 100 | 11 39 54 | 11 39 | A. P. |
| | 9 | II. | | Last seen | E. Eq. | 210 | 11 39 59 | | S. D. |
| | 9 (*h*) | I. | Ecl. R. | First seen | Lassell Refl. | 350 | 12 44 33 | 12 44 46 | H. T. |
| | 9 | I. | | First seen | Altaz. | 100 | 12 44 43 | | S. D. |
| | 11 | II. | Tr. Egr. | First contact | E. Eq. | 210 | 8 44 5 | | A. D. |
| | 11 | II. | | Bisection | ,, | ,, | 8 46 10 | 8 48 | ,, |
| | 11 | II. | | Last contact | ,, | ,, | 8 49 34 | | ,, |
| | 22 | III. | Ecl. R. | First seen | ,, | 70 | 8 46 28 | 8 43 44 | J. P. |
| | 25 (*i*) | I. | | First seen | Simms' Eq. | 220 | 11 2 5 | 11 1 34 | H. T. |
| | 27 | II. | | First seen | E. Eq. | 210 | 9 51 57 | 9 52 | H. |
| | 29 | III. | Occ. R. | Bisection | Altaz. | 100 | 9 23 53 | 9 23 | R. W. |
| | 29 | III. | | Last contact | ,, | ,, | 9 26 13 | | ,, |
| | 29 (*j*) | III. | Ecl. D. | Began to fade | E. Eq. | 210 | 9 57 24 | 9 59 | A. D. |
| | 29 | III. | | Last seen | ,, | ,, | 10 3 7 | | ,, |
| | 29 (*k*) | III. | Ecl. R. | First seen | Simms' Eq. | 220 | 12 41 32 | 12 41 19 | H. T. |

| Day of Obs. | | Satellite. | Phenomenon. | | Telescope. | Power. | Mean Solar Time of Observation. | Mean Solar Time of N.A. | Observer. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | h m s | h m s | |
| 1886, Apr. | 30 | IV. | Occ. D. | Bisection | Simms' Eq. | 220 | 8 27 1 | 8 33 | H.T. |
| | 30 (*l*) | IV. | | Last seen | ,, | ,, | 8 33 31 | | ,, |
| | 30 | IV. | Occ. R. | First seen | ,, | ,, | 9 55 31 | | ,, |
| | 30 | IV. | | Bisection | ,, | ,, | 10 0 38 | | ,, |
| | 30 (*m*) | IV. | | Last contact | ,, | ,, | 10 11 31 | 10 1 | L. |
| | 30 | IV. | | First seen | E. Eq. | 210 | 9 59 47 | | ,, |
| | 30 | IV. | | Last contact | ,, | ,, | 10 9 26 | | ,, |
| May | 2 (*n*) | I. | Ecl. R. | First seen | Lassell Refl. | 350 | 12 56 0 | 12 55 53 | H. T. |
| | 2 | II. | Tr. Ing. | First contact | ,, | ,, | 12 56 45 | | ,, |
| | 2 (*n*) | II. | | Bisection | ,, | ,, | 13 0 45 | 12 55 | ,, |
| | 2 | II. | | Last contact | ,, | ,, | 13 4 15 | | ,, |
| | 3 | I. | Tr. Egr. | First contact | Simms' Eq. | 220 | 9 18 38 | | T. |
| | 3 | I. | | Bisection | ,, | ,, | 9 20 22 | 9 22 | ,, |
| | 3 | I. | | Last contact | ,, | ,, | 9 22 22 | | ,, |
| | 4 | II. | Ecl. R. | First seen | E. Eq. | 210 | 12 28 43 | 12 28 48 | L. |
| | 4 | II. | | Full brightness | ,, | ,, | 12 30 28 | | ,, |
| | 6 | III. | Occ. D. | First contact | ,, | ,, | 9 54 55 | | ,, |
| | 6 | III. | | Last seen | ,, | ,, | 10 3 33 | | ,, |
| | 6 | III. | | First contact | Altaz. | 100 | 9 54 7 | 9 57 | R. W. |
| | 6 | III. | | Bisection | ,, | ,, | 9 57 17 | | ,, |
| | 6 | III. | | Last seen | ,, | ,, | 10 0 47 | | ,, |

| Day of Obs. | | Satellite. | Phenomenon. | | Telescope. | Power. | Mean Solar Time of Observation. | Mean Solar Time of N.A. | Observer. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | h m s | h m s | |
| 1886, May | 6 | III. | Occ. R. | First seen | E. Eq. | 210 | 12 49 54 | 12 55 | R. W. |
| | 6 | III. | | Last contact | ,, | ,, | 12 56 55 | | ,, |
| | 6 | III. | Ecl. D. | Last seen | ,, | ,, | 13 58 17 | 13 57 55 | ,, |
| | 18 | I. | Ecl. R. | First seen | ,, | ,, | 11 13 29 | 11 13 30 | H. |
| | 18 | I. | | Full brightness | ,, | ,, | 11 14 53 | | ,, |
| | 20 | II. | Tr. Egr. | First contact | Simms' Eq. | 220 | 9 41 9 | 9 42 | L. |
| | 20 | II. | | Last contact | ,, | ,, | 9 47 9 | | ,, |
| | 27 | II. | Tr. Ing. | First contact | E. Eq. | 210 | 9 23 58 | 9 21 | T. |
| | 27 (o) | II. | | Bisection | ,, | ,, | 9 26 43 | | ,, |
| | 29 | II. | Ecl. R. | First seen | ,, | 140 | 9 36 29 | 9 36 53 | A. D. |
| | 29 | II. | | Full brightness | ,, | ,, | 9 41 2 | | ,, |
| July | 6 | III. | Tr. Egr. | Bisection | ,, | 210 | 9 39 31 | 9 40 | ,, |
| | 6 | III. | | Last contact | ,, | ,, | 9 42 25 | | ,, |

*Notes.*

(*a*) Observations considered good. (*b*) Limb of planet somewhat tremulous, but satellite well defined.
(*c*) Satellite much brighter than *Jupiter*. (*d*) The time recorded for bisection is probably too early.
(*e*) No trace of the satellite was visible at 12$^h$ 33$^m$ 30$^s$, when *Jupiter* was lost in cloud; on reappearing at the time recorded the satellite was seen with some distinctness. Thick cloud then came up.
(*f*) Time recorded very uncertain, as the sky was thick and the satellites were faint.
(*g*) Planet was obscured at times by cloud. (*h*) Definition very bad.
(*i*) Observed through a temporary break in the clouds, but considered a real observation of reappearance.
(*j*) Observation uncertain from cloud.
(*k*) Observed through cloud, but the planet was shining brilliantly when the satellite was first seen.
(*l*) Until 8$^h$ 35$^m$ there appeared to be a slight abruptness on *Jupiter's* limb at the point of disappearance, but the observer was inclined to consider this the effect of strain on the eye. (*m*) Satellite well clear at 10$^h$ 14$^m$ 30$^s$.
(*n*) Definition very bad owing to haze. (*o*) *Jupiter* diffused.

## *Occultation of γ Virginis*, 1886. By F. C. Penrose.

A few remarks on an observation of an occultation of γ *Virginis* on the 18th inst. may be interesting to the Royal Astronomical Society.

The morning was fine, but there were some slight clouds, and one was over the Moon near the time predicted for the reappearance, so that I could not see the grey Moon, and, as I was dependent on the position-angle at the vertex, could not use a power high enough to separate the star properly, but I think the observation was more interesting and beautiful in consequence.

At G.M.T., ± say $2^s$, $16^h\ 33^m\ 32^s$, a bright flash showed the reappearance of $\gamma_1$, and exactly 10 seconds later was another flash, which seemed to double the brightness of the star.

The time was corrected by altitudes of east and west stars observed at nearly the same altitude and azimuth with a theodolite.

I got several positions of Barnard's Comet, particularly Nov. 29, Dec. 4, and Dec. 9, but they are probably liable to errors of two or three minutes of arc.

Approximate place of station, longitude $1^h\ 34^m\ 58^s$ E., and latitude $37°\ 58'\ 15''$ N.

*Athens*: 1886, *Dec.* 26.

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## *Occultation of Aldebaran*, Jan. 6, 1887. By the Rev. S. J. Johnson, M.A.

The occultation of *Aldebaran* on the 6th was observed here very favourably. Disappearance at $12^h\ 12^m\ 49^s$ was instantaneous; not the slightest lingering or projection on the limb, though a portion of the Moon's dark limb was left, and the sky around was perfectly clear. The star seemed to lose its redness as the Moon approached it; the emersion at $13^h\ 14^m\ 5^s$ not nearly so sudden. Star seemed to creep out leisurely from a point just north of the Mare Crisium, but some haze was present. Power 50 employed, on $3\frac{1}{4}$-inch. Time by sextant.

*Melplash Vicarage, Dorset*:
1887, *Jan.* 10.

## *Observations of Comet f 1886 (Barnard), made at the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer Royal.*)

The observations were made with the East or Sheepshanks Equatorial, aperture 6·7 inches, by taking transits over two cross-wires at right angles to each other, and each inclined 45° to the parallel of Declination.

*Comet f 1886 (Barnard).*

| 1886. | Greenwich Mean Solar Time. | Observer. | ☄−✱ R.A. | Corr. for Par. and Refract. in R.A. | ☄−✱ N.P.D. | Corr. for Par. and Refract. in N.P.D. | No. of Comp. | Apparent R.A. | Apparent N.P.D. | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | | m s | s | ′ ″ | ″ | | h m s | ° ′ ″ | |
| Dec. 14 | 5 15 41 | H. T. | +1 16·50 | +0·40 | − 8 38·2 | −6·6 | 3 | 17 33 9·80 | 74 55 57·4 | *a* |
| 14 | 5 30 1 | H. T. | −2 43·43 | +0·40 | +10 43·6 | −5·2 | 3 | 17 33 19·57 | 74 56 12·8 | *b* |
| 16 | 5 17 25 | H. | −0 11·33 | +0·30 | + 3 20·4 | −5·7 | 3 | 17 51 42·07 | 76 1 55·6 | *c* |
| 16 | 5 35 27 | H. | −0 48·90 | +0·40 | + 4 38·7 | −5·7 | 2 | 17 51 49·80 | 76 2 16·2 | *d* |

*Mean Places of Comparison Stars.*

| Star's Name. | R.A. 1886·0. | N.P.D. 1886·0. | Authority. |
|---|---|---|---|
| | h m s | ° ′ ″ | |
| (*a*) W.B. (2) XVII. 929–30 | 17 31 52·19 | 75 4 49·9 | Weisse's Bessel (2) |
| (*b*) W.B. (2) XVII. 1110–11 | 17 36 1·89 | 74 45 42·4 | Washington Catalogue 1860 |
| (*c*) W.B. XVII. 1033 | 17 51 52·31 | 75 58 53·2 | Weisse's Bessel |
| (*d*) W.B. XVII. 1057 | 17 52 37·62 | 75 57 52·3 | ,, ,, |

The observations are corrected for parallax and refraction. The initials H. T. and H. are those of Mr. Turner and Mr. Hollis respectively.

## *Sextant Observations of Comets Fabry and Barnard.*

(*Communicated by Captain H. Toynbee.*)

### *Comet Fabry.*

Observations made on board the ship "Earl of Shaftesbury," by Captain Wm. Randall.

1886, May 5, P.M. ($9^h\ 1^m\ 30^s$ G.M.T.), Lat. 4° 12′ N. Long. 22° 0′ W.

| | | ° | ′ |
|---|---|---|---|
| Nucleus of Comet to *Sirius* | ... ... ... | 13 | 50 |
| " " *Bellatrix* | ... ... | 23 | 54 |

1886, May 7: $8^h\ 24^m\ 4^s$ Astronomical G.M.T. Lat. 3° 36′ N.; Long. 20° 0′ W.

| | | ° | ′ | ″ |
|---|---|---|---|---|
| Nucleus to *Sirius* | ... ... ... ... | 8 | 23 | 20 |
| " " *Bellatrix* | ... ... ... ... | 30 | 34 | |

### *Comet Barnard.*

Observations made on board the s.s. "Neto," by Captain Wm. G. Browne. Ship's position, Lat. 31° 54′ N.; Long. 67° 53′ W.

| | h | m | s | | ° | ′ | ″ |
|---|---|---|---|---|---|---|---|
| Dec. 4 | 21 | 49 | 25 | Nucleus to *Arcturus* | 24 | 21 | 20 |
| | | 57 | 13 | " " *Dubhe* ... | 66 | 33 | 0 |
| | 22 | 6 | 4 | " " *Spica* ... | 47 | 32 | 20 |

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## *Note on the Electric Illumination of the Armagh Refractor.*
By J. L. E. Dreyer, Ph.D.

As inquiries have been made from several sides about the system of electric illumination adapted to the 10-inch Refractor at the Armagh Observatory by Mr. Grubb, it may be of use to give a short description of it.

The principal difficulty of connecting the eyepiece and other parts of an Equatorial with a battery is the necessity of the observer being able to turn the telescope about, and even to reverse the instrument, without getting it entangled with the connecting wires. This difficulty Mr. Grubb has obviated in a very neat manner by letting the current pass through two insulated brass rings, one of which is attached round the upper end of the polar pillar, and the other round the end of the Declination axis away from the telescope. The current passes from these rings through

brass combs sliding on them, and moving with the telescope respectively in Right Ascension and in Declination. The rings are kept clean by being from time to time rubbed with sand-paper.

The bichromate battery is placed in the porch to the east of the dome, and the wires are carried under the floor. One wire ends in a binding screw on the base casting of the Equatorial; the other passes through the base, along the outside of the polar pillar to the first of the above-mentioned rings. From the comb sliding on this the wire passes to the ring on the Declination axis; and from the comb sliding on this a wire runs along the counterpoise to the end of the Declination axis, through this and out through the "cradle" of the telescope down to the eye-end of the latter. I have here fixed a commutator, with four holes in it; by sticking a brass peg into one of these the current is sent to the lamp giving bright field illumination, or to the lamp illuminating the wires on a dark field, or to the lamp illuminating the Declination circle, or to a small hand-lamp used for throwing light on the micrometer and the note-book. From each of these lamps a wire goes to some metallic part of the telescope. The bright wire lamp is enclosed in a small brass cylinder on the micrometer, while the bright-field lamp is placed at the side of the tube opposite the Declination axis, the light being reflected down to the eyepiece by a very small central mirror on an arm which the observer, if he wishes, can put out of the way of the pencil of light from the object-glass by pushing a rod which goes down to the eye-end. The hand-lamp consists of a short brass tube with a lens at one end, and closed at the other end by a piece of wood, through which pass the wires and an ebonite rod carrying the lamp; when not in use it hangs on one of the arms to which the finder is attached.

There is no arrangement for reading the R.A. circle from the eye-end: the observer has to stand on one of two steps east and west of the pier, and reads the circle by means of a magnifying lens and an electric lamp placed in a short tube, which, when not required, hangs on a wire holder on the south end of the pier. From this lamp an "earth wire" goes to the base of the telescope mounting, and contact is made simply by resting the brass tube against an uncovered portion of the principal wire from the battery.

The incandescent lamps are from Laing, Wharton & Down, 8 and 9 Holborn Viaduct, London; the glass globes are $\frac{7}{16}$ of an inch in diameter. The bichromate battery has four cells, but only three are required for the micrometer, and one or two would be enough for illuminating the circles. The cells are very large, the glass jars being 9 inches high and 6 inches in diameter. To the metallic lids are fastened four carbons, $6\frac{1}{2}$ by $2\frac{1}{2}$ inches, and the zinc plate is 9 inches by 3 inches. By keeping the zinc plates lifted above the acid when not in use they last a long time. The whole arrangement has been found extremely convenient and clean.

## *Meteors with Curved Paths.* By W. F. Denning.

The term "erratic" applied by Mr. Hopkins to such meteors as display curved paths appears to me inappropriate. Erratic meteors are usually understood to refer to such of these bodies as belong to unknown systems, and are therefore synonymous with sporadic meteors. The title has also been employed to denote meteors which, though probably emanating from known showers, exhibit a certain discordance in their directions, though such discordance may have been induced by perturbations exercised upon them far beyond our atmosphere, and has nothing to do with the curved paths they sometimes pursue when under ignition. The term adopted by Mr. Hopkins is not expressive of the peculiarity to which he refers it. Such words as devious, sinuous, deflected, or tortuous meteors would be preferable, as conveying a distinct idea of the anomalous flights alluded to.

As a rule, I believe the alleged crooked paths are nothing more than mere impressions. The curious flickering in the light of individual meteors often giving rise to considerable alternations in their apparent brilliancy, combined with the fact that these phenomena rarely last long enough to ensure a steady view, occasion the idea of curved flights. The observer is seldom looking towards the exact place of a meteor's course, and the glimpse he obtains is more or less hurried, imperfect, and erroneous.

On December 20, 1886, $13^h\ 11^m$, I was watching for shooting stars and looking towards the immediate region of *Gemini* and *Cancer*, when suddenly a brightish meteor shone out north of $\beta$ *Leonis*. Instantly directing my eyes to the spot, I caught the end-course well, and received a very strong impression that the path was much crooked or curled, but about $1\frac{1}{2}$ sec. later a bright streak of phosphorescence came out on the course of the meteor, and I saw it was perfectly straight along its whole length. My idea as to the bent path was therefore quite illusory, and due to the scintillations of the meteor in its rapid flight which I had seen but imperfectly. I may add, that of some thousands of meteor streaks and trains observed here at various times very few have shown decided curvature.

In 1885, out of a total of 1,334 meteors recorded (omitting Andromedes of November 27), I noticed four which were conspicuously curved. In 1886 I saw 1,431 meteors, of which about fifteen exhibited the same peculiarity in a striking degree. One of the best examples of these was recorded on December 25, 1886, $8^h\ 22^m$. The meteor was 3rd mag. and moved very slowly

from between $\alpha$ and $\theta$ *Geminorum*; at the end it curved upwards so:—


Meteors are not infrequently broken during their flights and are observed to wax and wane several times before final disappearance. The large meteor of November 17, 1886, revived seven or eight times during its long flight of 63°, which it performed in seven seconds. Fireballs of the finest type are often accompanied with a series of outbursts and brilliant flashes directly resulting from increased combustion at certain points of their courses. Meteor streaks and trains are sometimes separated into three or four visible parts, but they are almost invariably sections of a straight line until they begin drifting under the influence of atmospheric currents, which occasionally mould them into grotesque, serpentine forms before they entirely fade from view.

As to the meteor of December 4, 1886, quoted by Mr. Hopkins, the phenomenon he describes must have been due, as Colonel Tupman suggested, to the nearly simultaneous appearance of two meteors with parallel paths, and hence, presumably, belonging to the same radiant. But the difference of 30′ is so small that it seems to me quite inappreciable when the circumstances of such observations are considered. Occasionally the beginning or end point of a meteor's flight, when near prominent stars, may be noted very accurately; but the details of the slight curve and secondary raised track of the meteor described by Mr. Hopkins would be far too trivial to be noticed by my eye or, I venture to affirm by any other eye not endowed with extraordinary powers.

*Bristol*: 1886, *Dec.* 31.

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*Erratum* (in some copies).

*Monthly Notices*, vol. xlvii., page 56, the 8th and 9th lines from the top should be inserted between the 2nd and 3rd lines from the top of page 55.

# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY.

Vol. XLVII. February 11, 1887 No. 4


J. W. L. Glaisher, M.A., F.R.S., President, in the Chair.

## Report of the Council to the Sixty-seventh Annual General Meeting of the Society.

The following table shows the progress and present state of the Society:—

| | Compounders | Annual Subscribers | Mathematical Society | Total Fellows | Associates | Patron | Grand Total |
|---|---|---|---|---|---|---|---|
| December 31, 1885 ... ... | 224 | 374 | 3 | 601 | 48 | 1 | 650 |
| Since elected ... ... ... | +3 | +20 | ... | ... | +2 | ... | ... |
| Deceased ... ... ... ... | −4 | −12 | ... | ... | −1 | ... | ... |
| Resigned ... ... ... ... | ... | −5 | ... | ... | ... | ... | ... |
| Expelled ... ... ... ... | ... | −4 | ... | ... | ... | ... | ... |
| Removals ... ... ... ... | +2 | −2 | ... | ... | ... | ... | ... |
| December 31, 1886 ... ... | 225 | 371 | 3 | 599 | 49 | 1 | 649 |

*Mr. Common's Account as Treasurer of the Royal*

RECEIPTS.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Balance at Bankers', Jan. 1, 1886 ... ... | 395 | 2 | 7 | | | |
| " in hand of Assistant Secretary on account of Turnor and Horrox Funds ... ... | 22 | 7 | 5 | | | |
| | | | | 417 | 10 | 0 |
| Half-year's dividend on £7,500 Consols ... ... | 108 | 15 | 0 | | | |
| " " £5,700 New 3 per cent. Stock ... ... ... | 82 | 13 | 0 | | | |
| " " £7,500 Consols ... ... | 108 | 15 | 0 | | | |
| " " £5,700 New 3 per cent. Stock ... ... ... | 82 | 13 | 0 | | | |
| Dividends on £500 Metropolitan Stock ... ... | 14 | 10 | 0 | | | |
| | | | | 397 | 6 | 0 |
| Received on account of Subscriptions: | | | | | | |
| Arrears ... ... ... ... ... ... | 161 | 14 | 0 | | | |
| 260 Annual Contributions for 1886 ... ... | 546 | 0 | 0 | | | |
| 4 " " 1887 ... ... | 8 | 8 | 0 | | | |
| 21 Admission Fees ... ... ... ... | 44 | 2 | 0 | | | |
| 18 First Contributions ... ... ... ... | 31 | 10 | 0 | | | |
| | | | | 791 | 14 | 0 |
| Composition Fees ... ... ... ... | | | | 105 | 0 | 0 |
| Sales of Publications: | | | | | | |
| At Williams and Norgate's, 1885 ... ... | 29 | 15 | 7 | | | |
| At Society's Rooms, 1886 ... ... ... | 38 | 7 | 9 | | | |
| | | | | 68 | 3 | 4 |
| | | | | £1,779 | 13 | 4 |

Audited and found correct, Jan. 8, 1887.

Robt. Bryant.

Robt. J. Lecky.

Herbert Sadler.

*Astronomical Society, from Dec.* 31, 1885, *to Dec.* 31, 1886.

## EXPENDITURE.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Assistant Secretary: Salary ... ... .. | 225 | 0 | 0 | | | |
| ,, ,, for assistance in editing Society's Publications ... | 50 | 0 | 0 | | | |
| | | | | 275 | 0 | 0 |
| Income Tax and House Duty ... ... .. | | | | 13 | 2 | 6 |
| Fire Insurance ... ... ... ... .. | | | | 7 | 16 | 6 |
| Printing ... ... ... ... ... .. | 577 | 11 | 0 | | | |
| Engraving and Lithography ... ... .. | 4 | 8 | 0 | | | |
| Computation of Ephemerides in *Monthly Notices* ... | 50 | 0 | 0 | | | |
| | | | | 631 | 19 | 0 |
| Turnor and Horrox Funds: purchase of Books for Library ... ... ... ... ... .. | 21 | 1 | 5 | | | |
| Binding Books in Library ... ... ... ... | 19 | 16 | 9 | | | |
| Preparation of Library Catalogue ... ... ... | 25 | 0 | 0 | | | |
| | | | | 65 | 18 | 2 |
| House Expenses ... ... ... ... ... .. | 34 | 13 | 5 | | | |
| Wages ... ... ... ... ... ... .. | 31 | 4 | 0 | | | |
| Postage, &c. ... ... ... ... ... .. | 58 | 13 | 1 | | | |
| Carriage of Parcels, &c. ... ... ... .. | 2 | 6 | 6 | | | |
| Stationery and Office Expenses ... ... ... | 6 | 12 | 9 | | | |
| Expenses of Meetings ... ... ... ... | 20 | 0 | 0 | | | |
| Coals and Gas ... ... ... ... ... | 56 | 7 | 9 | | | |
| Fittings and Repairs... ... ... ... ... | 12 | 16 | 6 | | | |
| Sundries ... ... ... ... ... ... | 4 | 12 | 11 | | | |
| | | | | 227 | 6 | 11 |
| Gold Medals ... ... ... ... ... ... | | | | 52 | 10 | 0 |
| Portrait of Sir Isaac Newton ... ... ... | | | | 18 | 18 | 0 |
| Lee Fund ... ... ... ... ... ... | | | | 5 | 0 | 0 |
| Mrs. Jackson Gwilt's Annuity ... ... ... | | | | 8 | 19 | 0 |
| Bankers' Commission on Cheques ... ... ... | 0 | 2 | 4 | | | |
| Cheque Book ... ... ... ... ... ... | 0 | 8 | 4 | | | |
| | | | | 0 | 10 | 8 |
| Balance at Bankers', Dec. 31, 1886 ... ... ... | 434 | 2 | 9 | | | |
| Cheque not Credited in Pass Book ... ... ... | 2 | 2 | 0 | | | |
| Balance in hand of Assistant Secretary on account of Turnor and Horrox Fund ... ... | 21 | 6 | 0 | | | |
| ,, in hand of Assistant Secretary on Petty Cash Account ... ... ... ... ... | 1 | 18 | 3 | | | |
| | | | | 459 | 9 | 0 |
| Paid Balance due to Assistant Secretary, Jan. 1, 1886, on Petty Cash account ... ... ... | | | | 13 | 3 | 7 |
| | | | | 1,779 | 13 | 4 |

## *Assets and Present Property of the Society, Jan.* 1, 1887.

| | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| Balance at Bankers', including an amount of £40 16*s.* 3*d.*, being the accumulated interest of the Lee Fund, Dec. 31, 1886 | 434 | 2 | 9 | | | |
| Cheque not Credited in Pass Book ... ... ... | 2 | 2 | 0 | | | |
| „ in hand of Assistant Secretary on account of Turnor and Horrox Funds ... ... | 21 | 6 | 0 | | | |
| „ in hand of Assistant Secretary on Petty Cash account ... ... ... ... | 1 | 18 | 3 | | | |
| | | | | 459 | 9 | 0 |
| Due on account of Subscriptions: | | | | | | |
| 4 Contributions of 4 years' standing ... | 33 | 12 | 0 | | | |
| 14 „ 3 „ ... | 88 | 4 | 0 | | | |
| 30 „ 2 „ ... | 126 | 0 | 0 | | | |
| 67 „ 1 year's standing ... | 140 | 14 | 0 | | | |
| 3 Admission Fees and First Contributions ... | 9 | 9 | 0 | | | |
| | 397 | 19 | 0 | | | |
| Less 4 Contributions paid in advance ... | 8 | 8 | 0 | | | |
| | | | | 389 | 11 | 0 |
| Due from Messrs. Williams and Norgate for sales of Publications during 1886 ... ... ... ... ... | | | | 37 | 15 | 10 |

£7,500 Consols, including the Lee Fund, the Turnor Fund, and the Horrox Memorial Fund.

£5,700 New 3 per cent. Stock, including Mrs. Jackson Gwilt's gift (£300).

£500 Metropolitan Board of Works Stock.

Astronomical and other Manuscripts, Books, Prints, Instruments; and Furniture.

Unsold Publications of the Society.

Three Gold Medals.

*Report of the Auditors.*

We, being the duly appointed Auditors, beg to lay before this Annual General Meeting of the Royal Astronomical Society the following Report:—

We have examined the Treasurer's account, and have found and certified the same to be correct. The receipts and expenditure for the past year are as stated in the Treasurer's account. The cash in hand on December 31, 1886, including the balance at the bankers', amounted to 459*l*. 9*s*.

The funded property is the same as at the end of last year.

The books, instruments, and other effects have been examined and found to be in a satisfactory condition, so far as their safe keeping is concerned.

We have laid on the table a list of the names of those Fellows who are in arrear for sums due at the last Annual General Meeting, with the amount due against each Fellow's name.

(Signed) Robt. J. Lecky,
Robt. Bryant,
Herbert Sadler.

Stock in hand of volumes of the *Memoirs*:—

| Vol. | At Society's Rooms | At Williams & Norgate's | Vol. | At Society's Rooms | At Williams & Norgate's |
|---|---|---|---|---|---|
| I. Part 1 | 7 | ... | XXIX. | 411 | ... |
| I. Part 2 | 43 | ... | XXX. | 159 | 1 |
| II. Part 1 | 56 | ... | XXXI. | 143 | ... |
| II. Part 2 | 21 | ... | XXXII. | 154 | 1 |
| III. Part 1 | 67 | 1 | XXXIII. | 164 | ... |
| III. Part 2 | 86 | 1 | XXXIV. | 164 | 4 |
| IV. Part 1 | 80 | 3 | XXXV. | 108 | 6 |
| IV. Part 2 | 92 | 3 | XXXVI. | 198 | 10 |
| V. | 106 | 4 | XXXVII. Part 1 | 339 | 8 |
| VI. | 125 | 3 | XXXVII. Part 2 | 287 | 8 |
| VII. | 145 | 3 | XXXVIII. | 276 | 1 |
| VIII. | 127 | 3 | XXXIX. Part 1 | 248 | 4 |
| IX. | 134 | 3 | XXXIX. Part 2 | 253 | 4 |
| X. | 146 | ... | XL. | 268 | 2 |
| XI. | 151 | ... | XLI. | 417 | 1 |
| XII. | 159 | ... | XLII. | 239 | 4 |
| XIII. | 163 | ... | XLIII. | 243 | 1 |
| XIV. | 370 | 3 | XLIV. | 224 | 1 |
| XV. | 140 | ... | XLV. | 260 | 1 |
| XVI. | 165 | ... | XLVI. | 242 | 3 |
| XVII. | 147 | 1 | XLVII. Part 1 | 3 | ... |
| XVIII. | 146 | ... | XLVII. Part 2 | 19 | ... |
| XIX. | 152 | ... | XLVII. Part 3 | 2 | ... |
| XX. | 142 | ... | XLVII. Part 4 | 10 | ... |
| XXI. Part 1 | 314 | ... | XLVII. Part 5 | 10 | ... |
| XXI. Part 2 | 99 | ... | XLVII. Part 6 | 10 | ... |
| XXI. 1 & 2 (together) | 61 | ... | XLVII. | 240 | 2 |
| XXII. | 164 | ... | XLVIII. Part 1 | 310 | 3 |
| XXIII. | 150 | ... | XLVIII. Part 2 | 348 | 3 |
| XXIV. | 156 | ... | Index to *Memoirs* | 645 | 1 |
| XXV. | 166 | ... | | | |
| XXVI. | 172 | ... | | | |
| XXVII. | 422 | ... | | | |
| XXVIII. | 383 | ... | | | |

Stock in hand of volumes of the *Monthly Notices*:—

| Vol. | At Society's Rooms | At Williams & Norgate's | Vol. | At Society's Rooms | At W & No |
|---|---|---|---|---|---|
| I. | 68 | ... | XXV. | 7 | ... |
| II. | 69 | ... | XXVI. | 10 | ... |
| III. | ... | ... | XXVII. | 3 | ... |
| IV. | ... | ... | XXVIII. | 72 | 1 |
| V. | ... | ... | XXIX. | 51 | ... |
| VI. | 37 | ... | XXX. | 68 | 2 |
| VII. | 2 | ... | XXXI. | 96 | ... |
| VIII. | 139 | 2 | XXXII. | 118 | 5 |
| IX. | 25 | 2 | XXXIII. | 100 | 2 |
| X. | 174 | 1 | XXXIV. | 79 | 2 |
| XI. | 185 | 1 | XXXV. | 61 | 1 |
| XII. | 11 | 2 | XXXVI. | 32 | 1 |
| XIII. | 157 | 3 | XXXVII. | 39 | 3 |
| XIV. | 109 | 3 | XXXVIII. | 103 | 2 |
| XV. | 127 | 2 | XXXIX. | 108 | 1 |
| XVI. | 108 | 2 | XL. | 113 | 3 |
| XVII. | 137 | 1 | XLI. | 114 | 5 |
| XVIII. | 166 | ... | XLII. | 122 | 2 |
| XIX. | 56 | ... | XLIII. | 122 | 2 |
| XX. | 35 | ... | XLIV. | 125 | 5 |
| XXI. | 18 | ... | XLV. | 130 | 3 |
| XXII. | 33 | ... | XLVI. | 137 | 4 |
| XXIII. | 19 | ... | Index to *Monthly Notices* | 568 | 1 |
| XXIV. | 24 | ... | | | |

Library Catalogue ... ... ... ... ... ... 668

In addition to the above volumes of the *Monthly Notices*, the ›ciety has a considerable stock of separate numbers of nearly the volumes. With the exception, however, of Vols. XXXVI. XLVI. no complete volumes can be formed from the separate ıbers in stock.

*Instruments belonging to the Society.*

'o. 1. The *Harrison* clock.
, 2. The *Owen* portable circles, by Jones.
3. The *Beaufoy* circle.
4. The *Beaufoy* transit instrument.

No. 5. The *Herschel* 7-foot telescope.
„ 6. The *Greig* universal instrument, by Reichenbach and Ertel. The transit telescope, by Utzschneider and Fraunhofer, of Munich.
„ 7. The *Smeaton* equatoreal.
„ 8. The *Cavendish* apparatus.
„ 9. The 7-foot Gregorian telescope (late Mr. Shearman's).
„ 10. The variation transit instrument (late Mr. Shearman's).
„ 11. The universal quadrat, by Abraham Sharp.
„ 12. The *Fuller* theodolite.
„ 13. The standard scale, by Troughton and Simms.
„ 14. The *Beaufoy* clock, No. 1.
„ 15. The *Beaufoy* clock, No. 2.
„ 16. The *Wollaston* telescope.
„ 17. The *Lee* circle.
„ 18. The *Sharpe* reflecting circle.
„ 19. The *Brisbane* circle.
„ 20. The *Baker* universal equatoreal.
„ 21. The *Reade* transit.
„ 22. The *Matthew* equatoreal, by Cooke.
„ 23. The *Matthew* transit instrument.
„ 24. The *South* transit instrument.
„ 25. A sextant, by Bird (formerly belonging to Captain Cook).
„ 26. A globe showing the precession of the equinoxes.
The *Sheepshanks* collection:—
„ 27. (1) 30-inch transit instrument, by Simms, with level and two iron stands.
„ 28. (2) 6-inch transit theodolite, with circles divided on silver; reading microscopes, both for altitude and azimuth; cross and siding levels; magnetic needle; plumbline; portable clamping foot and tripod stand.
„ 29. (3) Equatoreal stand and clock movement for $4\frac{6}{10}$-inch telescope (telescope lost); double-image micrometer; two wire micrometers; object-glass micrometer.
„ 30. (4) $3\frac{1}{4}$-inch achromatic telescope, with equatoreal stand; double-image micrometer; one terrestrial and three astronomical eyepieces.
„ 31. (5) $2\frac{3}{4}$-inch achromatic telescope, with stand; one terrestrial and three astronomical eyepieces.
„ 33. (7) 2-foot navy telescope.
„ 34. (8) Transit instrument of 45 inches focal length; with iron stand and also Ys for fixing to stone piers; two axis levels.
„ 35. (9) Repeating theodolite, by Ertel, with folding tripod stand.
„ 36. (10) 8-inch pillar sextant, by Troughton, divided on platinum, with counterpoise stand and artificial horizon.

No. 37. (11) Portable zenith telescope and stand, $2\frac{3}{4}$-inch aperture and 26 inches focal length; 10-inch horizontal circle and 8-inch vertical circle, read to 10″ by two verniers to each circle.

„ 38. (12) 18-inch Borda repeating circle, by Troughton, $2\frac{1}{8}$-inch aperture and 24 inches focal length; the circles divided on silver, the horizontal circle being read by four verniers, and the vertical circle by three verniers, each to 10″.

„ 39. (13) 8-inch vertical repeating circle, with diagonal telescope, by Troughton and Simms; circle divided on silver, reading to 10″; a 5-inch circle at eye-end, reading to single minutes; horizontal circle 9 inches diameter in brass, reading to single minutes.

„ 40. (14) A set of surveying instruments, consisting of a 12-inch theodolite for horizontal angles only, reading to 10″; two sets of adjusting plates; tripod stand with enclosed telescope; heavy stand for theodolite; Y piece of level; two large and three small ground-glass bubbles divided; level collimator, object-glass $1\frac{5}{8}$-inch diameter and 16 inches focal length; micrometer eyepiece, comb, and wires; mercury bottle and trough.

„ 41. (15) Level collimator with object-glass $1\frac{7}{8}$-inch diameter and 16 inches focal length; stand, rider-level, and fittings.

„ 42. (16) 10-inch reflecting circle by Troughton, reading by three verniers to 20″; counterpoise stand; artificial horizon, with mercury; two tripod stands.

„ 43. (17) Hassler's reflecting circle, by Troughton, with counterpoise stand.

„ 44. (18) 6-inch reflecting and repeating circle, by Troughton and Simms, contained in three boxes, two of which form stands. Circle divided on silver, reading to single minutes; two inside arcs divided to single degrees, 150 degrees on each side; artificial horizon and mercury.

„ 45. (19) 5-inch reflecting and repeating circle, by Lenoir, of Paris.

„ 46. (20) Reflecting circle, by Jecker, of Paris, 11 inches in diameter, with one vernier reading to 15″.

„ 47. (21) Box sextant; reflecting plane and level.

„ 48. (22) Prismatic compass, by Troughton and Simms.

„ 49. (23) Mountain barometer.

„ 50. (24) Prismatic compass, by Thomas Jones, mounted with a cylindrical lens.

„ 51. (25) Ordinary $4\frac{1}{2}$-inch compass with needle.

„ 52. (26) Dipping needle, by Robinson.

53. (27) Compass needle, mounted for variation.

No. 54. (28) Magnetic intensity needle, by Meyerstein, o Göttingen; a strongly fitted brass box with heav magnet; filar suspension.

„ 55. (29) Box of magnetic apparatus.

„ 56. (30) Hassler's reflecting circle, by Troughton; 10½-inch reflecting and repeating circle, with stan and counterpoise, divided on platinum with tw movable and two fixed indices; four verniers reading to 10″.

„ 57. (31) Box sextant and glass plane artificial horizon by Troughton and Simms.

„ 58. (32) Plane 2⅜-inch speculum, artificial horizon, an stand.

„ 59. (33) 2½-inch circular level horizon, by Dollond.

„ 60. (34) Artificial horizon, roof, and trough; the troug 8¼ by 4½ inches; tripod stand.

„ 61. (35) Set of drawing instruments, consisting o 6-inch circular protractor and common protracto T-square; one beam compass.

„ 62. (36) A pantagraph.

„ 63. (37) A noddy.

„ 64. (38) A small Galilean telescope with object-glass o rock crystal.

„ 65. (39) Five levels.

„ 66. (40) 18-inch celestial globe.

„ 67. (41) Varley stand for telescope.

„ 69. (43) Telescope, with object-glass of rock crystal.

„ 71. Portable altazimuth tripod.

„ 72. Four polarimeters.

„ 74. Registering spectroscope, with one large prism.

„ 76. Two five-prism direct-vision spectroscopes.

„ 78. 9¼-inch silvered-glass reflector and stand, b Browning.

„ 79. Spectroscope.

„ 80. A small box, containing three square-headed Nicol' prisms; two Babinet's compensators; two double image prisms; three Savarts; one positive eyepiec with Nicol's prism; one dark wedge.

„ 81. A back-staff, or Davis' quadrant.

„ 82. A nocturnal or star dial.

„ 83. An early non-achromatic telescope, of about 3 fee focal length, in oak tube, by Samuel Scatliff London.

„ 84. A Hollis observing chair.

„ 85. Double image micrometer, by Troughton and Simms.

„ 86. 4½-inch Gregorian reflecting telescope, by Shor with altazimuth stand and 6-inch altitude an azimuth circles and two eyepieces.

„ 87. 3½-inch Gregorian reflecting telescope with woode tripod stand.

No. 88. Pendulum with 5-foot brass suspension rod, working on knife edges, by Thomas Jones.

„ 89. A Rhabdological Abacus. A contrivance invented by Mr. H. Goodwyn, consisting of a box filled with compartments, in which are square rods covered with numbers, which can be arranged so as to facilitate the labour of multiplying high numbers.

„ 90. An Arabic celestial globe of bronze, $5\frac{3}{4}$ inches in diameter.

„ 91. Astronomical time watchcase, by Professor Chevallier.

„ 92. 2-foot protractor, with two moveable arms, and vernier.

„ 93. Beam compass, in box.

„ 94. 2-foot navigation scale.

„ 95. Stand for testing measures of length.

„ 96. Artificial planet and star, for testing the measurement of a fixed distance at different position-angles.

„ 97. 12-cell Leclanché battery.

„ 98. 2 feet 6 inch navy telescope with object-glass $2\frac{1}{4}$ inches, by Cooke, with portable wooden tripod stand.

„ 99. 12-inch transit instrument, by Fayrer & Son, with level and portable stand.

„ 100. 9-inch transit instrument, with level and iron stand.

„ 101. Small equatoreal sight instrument, by G. Adams, London.

„ 102. Sun-dial, by Troughton.

„ 103. Sun-dial, by Casella.

„ 104. Sun-dial

„ 105. Box sextant, by Troughton and Simms.

„ 106. Prismatic compass, by Schmalcalder, London.

„ 107. Compass, by C. Earle, Melbourne.

„ 108. Prismatic compass, by Negretti and Zambra.

„ 109. Dipleidoscope, by E. Dent.

„ 110. Abney level, by Elliott.

„ 111. Pocket spectroscope, by Browning.

„ 112. Small brass astrolabe.

„ 113. Double sextant, by Jones.

„ 114. Two models, illustrating the effects of circular motions.

„ 115. A cometarium.

„ 116. A pair of 18-inch globes.

„ 117 }
„ 118 } Two old sun dials.

„ 119. Specimens of Diffraction gratings, by Prof. W. A. Rogers.

No. 120. A 6-prism spectroscope, by Browning.
„ 121. Spitta's Improved maximum and minimum thermometer.
„ 122. A 6-inch speculum, with flat; the speculum said to be by Sir W. Herschel, and re-figured by Sir J. Herschel.
„ 123. A 6-inch refracting telescope, by Grubb, with 3 eyepieces.

The following instruments are lent, during the pleasure of the Council, to the undermentioned persons:—

No. 4. The *Beaufoy* transit instrument, to the Observatory, Kingston, Canada.
„ 22. The *Matthew* equatoreal, to Mr. J. Brett.
„ 23. The *Matthew* transit, to Captain W. Noble.
„ 29. (3) Equatoreal mounting, clock movement, and stand, to Mr. W. Peck.
„ 30. (4) 3¼-inch equatoreal and stand, to Mr. H. Sadler.
„ 34. (8) Transit instrument, to Prof. C. Pritchard.
„ 69. (43) Telescope, with rock-crystal object-glass, to Dr. W. Huggins.
„ 78. Two eyepieces, to Mr. R. T. A. Innes.

*The Gold Medal.*

The Council have awarded the Society's Gold Medal to Mr. G. W. Hill for his researches on the Lunar Theory. The President will lay before the Society the grounds upon which the award has been founded.

*Lunar Computations.*

The computations, made by means of the Government Grant of 320*l.* for the purpose of comparing the Greenwich lunar observations 1847 to 1861 with Hansen's *Tables de la Lune*, have been completed, and will shortly be published.

## OBITUARY.

The Council regret that they have to record the loss by death of the following Fellows and Associate during the past year:—

Fellows:—Major-General J. T. Boileau.
W. W. Boreham.
D. T. Evans.
W. S. Gillett.
George Hamilton.
R. J. Mann.
Rev. J. Pearson.
H. S. Redpath.
Rev. S. H. Saxby.
Admiral Sir C. F. A. Shadwell.
David Smith.
Captain F. Smith.
Edwin Story.
Rev. S. K. Swann.
C. G. Talmage.
William Tomlinson, jun.

Associate:—Theodor von Oppolzer.

MAJOR-GENERAL JOHN THEOPHILUS BOILEAU, R.E., F.R.S., was born on May 26, 1805, at Calcutta, where his father, Mr. Thomas Boileau, was chief magistrate. This family claim descent from Etienne Boileau, Lord of Castelnau and St. Croix, who was left by Louis IX. as Constable and Provost of France when he went crusading; and Jacques Boileau, the poet, through Charles, Baron of Castelnau, who was driven from France at the time of the Revocation of the Edict of Nantes.

Mr. Boileau died in 1806, and his widow, with her two sons, John and Henry, then came to England and settled at Bury St. Edmunds, where the boys attended the grammar school, under Mr. Blomfield, at which John is said to have exhibited great capacity for languages. Soon after he was fourteen he received a nomination to a cadetship at Addiscombe, from which he passed brilliantly into the Bengal Engineers in December 1820. After the usual course of training at Chatham, under Sir C.

Pasley, he sailed for India, and reached Calcutta in September 1822, when little more than seventeen years of age. His energies were soon employed on the duties of the corps in building and repairing barracks, churches, bridges, and roads; and he soon acquired a reputation for the excellence of his work.

In 1836 he published in India (by lithography) "Traverse Tables to every Minute of the Quadrant"; and in 1839, when in England on furlough, these were printed and republished in London. In this latter year the Honourable Court of Directors of the East India Company selected Lieutenant Boileau for the charge of one of the three observatories which they undertook to support for magnetic and meteorological research. Simla was assigned as the charge of Lieutenant Boileau, and he was also directed to superintend the construction and despatch of instruments for the three observatories. After instruction by Prof. Humfrey Lloyd at Dublin, Lieutenant Boileau and the other two superintendents embarked (with the instruments) for India at the end of February 1840; and he finally reached Simla in October of that year, after leaving his colleagues and their instruments at Madras. During the voyage a series of meteorological observations was kept up, and on the way from Calcutta Boileau made observations of magnetical data at places at which he stopped. Work was commenced soon after his arrival at Simla in a temporary building, and the erection of the more permanent one was begun.

During the period prescribed for observation it appears that periodical abstracts were sent to Dr. Lloyd and the Royal Society, and Colonel Boileau, after the observatory was closed, was employed, in addition to other duties, till his retirement early in 1857, in reducing and printing his observations. On his leaving India the instruments and records were placed in store, and, having got mixed up with inflammable articles, the whole were in 1858 destroyed by fire. A portion of the meteorological results were published at Madras in 1851, and a further portion were published under General Boileau's care in 1872 by a grant from the India Office, procured by the Royal Society.

During his residence at Simla, General Boileau published from the Observatory press a set of astronomical, magnetic, and meteorological tables; some logarithmic tables and tables for computing time from extra-meridian observations; besides some other works of purely Indian interest.

After arriving finally in England in 1857, General Boileau's energies were devoted to such useful and charitable work as he could find. He soon became a member of the Committee of the Soldiers' Daughters' Home, and afterwards became Chairman. Later he joined that of the Royal School for Officers' Daughters. In 1860 he became a member of the 1st Middlesex (Victoria) Rifles, and served in that corps for six years as a private till his health prevented his longer attending regularly to drills, parades, &c. In 1867 he became a member of the Kensington Vestry,

and served zealously for thirteen years, earning the respect of his fellow vestrymen by his good sense, experience, and courtesy.

With endless humour and perpetually overflowing spirits, John Boileau, during his Indian career, was widely known for his eccentricities and practical jokes. Men would believe him capable of any joke that was not unkind. But he always had the confidence and regard of all who came in contact with him. Sir Henry Lawrence was among his companions at Addiscombe, and was his intimate friend to the last, while, in a long residence of seventeen years at Simla, he was brought into close contact with the rulers of India during that time without making any but friends; and so it would seem to have been after his settling in England. His fellow vestrymen, the members of the boards with which he was connected, and the staff and pupils of the schools he managed were all represented among the mourners at his funeral.

General Boileau was elected a Fellow of the Royal Society in January 1840. He served on the Council of the Royal Society, and was their representative on the governing body of Christ's Hospital. He died on November 9 last, after an illness of about six months.

He was elected a Fellow of this Society January 10, 1840.

William Wakeling Boreham was born at Haverhill, in Essex, on March 3, 1804, and received his early education at Saffron Walden, where he soon displayed great talent for mathematics and music.

Following his father's tastes, he at first became a brewer, and was in business in London and afterwards in Manchester; he subsequently returned to Haverhill, where he erected an observatory, and devoted himself industriously to observations of comets and minor planets. Many of his observations were published in the early volumes of the *Monthly Notices*.

Mr. Boreham was an ardent admirer of all science, and in his early life tried hard to promote the higher education of those in his native place. In later life he devoted his energies to education in all its branches.

He was for many years a Fellow of the Anthropological Society.

He was elected a Fellow of this Society April 11, 1845.

George Hamilton was born in Belfast in 1813. Removing to Liverpool at an early age, he was apprenticed to Mr. Bartain Haigh, builder. Soon after completing his term he was offered an appointment as architect, which he declined, having found his vocation to be that of a teacher. In 1836 he was appointed master of Mount Pleasant Schools, and amongst the children of the poor he worked out for several years his ideal course of instruction, which included, in addition to the usual branches, algebra, as far as quadratic equations, geometry, including the

first and second books of Euclid, and weekly lectures on chemistry and natural philosophy to both boys and girls.

While thus engaged he was appointed assistant and afterwards head master of the mathematical department of the evening school of the Liverpool Institute. From this class sprang "The Working Men's Science Association," to which Mr. Hamilton lectured nearly every week for two years to a working-class audience averaging 400 persons. In 1844 Mr. Hamilton lectured in Liverpool, Leeds, Bradford, and Chorley on "The Use of Science to Working Men," his aim being to establish free public evening lectures in every town in the kingdom, and to organise science teaching in every elementary school. But public opinion was then against the innovation. Mr. Hamilton was associated with the Liverpool Institute from 1840 to 1879 (when a serious accident obliged him to resign all his professional duties), successively holding the appointments of Teacher of Architectural Drawing and Building Construction, Teacher of Mathematics, Lecturer on Chemistry and Natural Philosophy in both Blackburne House and the High School, and in 1856 Professor of Chemistry in Queen's College (in connection with the London University).

In 1850 he was appointed first Lecturer on Chemistry and Teacher of Practical Pharmacy to the Liverpool Chemists' Association.

In 1856 he was elected a member of the Liverpool Compass Committee, to investigate the causes of deviation of the compass in iron ships.

He designed a self-registering compass, for recording the course of a ship at sea, indicating every change of tack and the exact time of change for the whole voyage. He also invented a self-registering thermometer, and a gas transferrer, or siphon, for transferring small quantities of gas for accurate measurement.

Mr. Hamilton was widely known as a teacher of science, and for many years successfully carried out a scheme for delivering a regular and systematic course of scientific instruction in middle-class schools—a task attempted by many before him, and rendered arduous from the expense and delicacy of much of the apparatus required, the difficulty of conveying it from place to place, the mental strain entailed by an average of twelve lectures weekly, and by the diversity of subjects, the course embracing astronomy, chemistry, geology, and natural philosophy. Nor, in his zeal for science, were the languages forgotten, each day having its apportioned task of classics and modern languages.

For several years, until prevented by failing health, he conducted the examinations for the Science Department of the Liverpool Council of Education.

Mr. Hamilton was a member of the Chemical Society and of the Society of Arts. He wrote "Glimpses of Nature," "Social Science," "Gravitation," "Physical Science," "On the Con-

servation of Force," "On Iron," "The Chemistry of the Gases," "On Dr. Medlock's Process of Filtering and Purifying Water," "The Gyroscope and Rotary Motion," "Note on Strychnine," "Chemistry in its Relation to the other Sciences," "Suggestions for a New System of Chemical Nomenclature," "Gaseous Exhalations and Miasmata as Causes of Nuisance and Disease," "Progressive Changes of Form in Rotating Spheroids," "High Tides and Colliery Explosions," "A Law of Elliptic Motion," &c.

Mr. Hamilton had the satisfaction, in the closing years of his life, of witnessing the adoption, in modified form, by the Liverpool Council of Education and the Liverpool School Board, of that system of scientific education which he had at the beginning of his career as a teacher regarded as a necessary part of primary instruction; and in the department of higher education his later years were cheered by the establishment of University College, Liverpool.

From his earliest years Mr. Hamilton had advanced views on education, but he was no theorist. In the face of opposition and many difficulties, he practised what he believed. Others have now entered into his labours, and the cause is making rapid progress. Mr. Hamilton's courteous manners, his devotion to duty, and his high intellectual attainments won for him the affection and esteem of all who knew him.

He was elected a Fellow of this Society January 12, 1855.

Robert James Mann was born in Norwich in January 1817. At an early age he evinced a great love of, and aptitude for, physical science. Botany was his first pursuit, and, while still a student, he published an excellent list of the flowering plants of the Norfolk district.

He was educated for the medical profession, and studied at University College. He took the M.R.C.S. and L.S.A. degrees in 1840, and for some years practised in Norfolk, continuing his scientific pursuits, and beginning to occupy himself with literary undertakings also. It was during this time that he published his first book, "The Planetary and Stellar Universe."

In 1853 domestic circumstances, connected with health, caused him partially to abandon the practice of his profession. In 1854 he became an M.D. of St. Andrews, and about this time was employed in assisting his old teacher and attached friend, Dr. C. J. B. Williams, in the revision and publication of his "Principles of Medicine," assistance, the value of which was generously acknowledged in the work itself, and again in the much more recently published "Memorials of Life and Work" of that eminent physician.

In 1857, on the invitation of Bishop Colenso, Dr. Mann left England for Natal, where he resided nine years, during seven of which he was Superintendent of Education for that colony; an office established by the then Governor, Mr. (now Sir John)

Scott, to which he received the first appointment. In this capacity he succeeded, working against great difficulties, in starting elementary schools for both the English and Dutch inhabitants, and ultimately in assisting those for the native population also. This, no doubt, is a noteworthy achievement in his life, and its value and the way in which it was accomplished have, since his death, been borne testimony to in the *Natal Mercury* of September 14 of last year, in the following words:—"For several years he gave up his time most unsparingly to a task which to him was a labour of love, and the measure of his personal success may be gauged by the extent to which his work suffered when his own part in it was withdrawn."

From his first arrival in Natal he also carried out day by day and recorded meteorological observations, the tabulated results of which are in the hands of the Meteorological Office. After his return to England he twice served as President of the Meteorological Society. While still in Natal he was, besides, the referee of the whole colony on all matters connected with science.

In 1862 he was the chief organiser of the exhibits the colony contributed to the great exhibition of that year, and he arranged and carried out a preliminary exhibition in Durban.

He returned from Natal in 1866, in consequence of receiving a special appointment from the Legislative Council to inaugurate a scheme of Government emigration to the colony. This he held for four years, during which, besides undertaking all the arduous work of his official position, he took charge of the arrangements of the Natal exhibits in the Paris Exhibition of 1867. He laboured gratuitously in promoting emigration to Natal for two years after his appointment as agent was withdrawn.

From about that time he ceased to have any special connection with the colony, and for the rest of his life devoted himself to the scientific and literary pursuits which had ever been congenial and delightful to him.

Of all the sciences which early engaged his attention and became subjects of study none excited so profound an interest or kept so permanent a hold upon his regard as that of astronomy. All through his life it was the one which he would have desired, had circumstances permitted, to make his chief pursuit and occupation. His first work was entitled "The Planetary and Stellar Universe." He was prompted to write it solely by his own profound sense and fervid appreciation of the grandeur and beauty of the subject of which it treated. This was followed, in 1850, by a smaller work on "The Achievements of Sidereal Astronomy in the middle of the Nineteenth Century." Later on he published "A Guide to Astronomical Science." He also furnished to *Chambers's Repository* a "History of the Moon."

Dr. Mann was for many years on the staff of the *Edinburgh Review*, and the admirable articles which he contributed to it on astronomical subjects are well known. His last piece of literary

work, indeed, was an article on "The Recent Progress of Astronomy," which appeared in the number for April of last year.

He was a popular and prolific writer, and was a frequent contributor to several magazines and reviews. The protection of buildings from lightning was a subject on which he wrote a good deal, and for which he did much valuable work.

In 1874 he was appointed Secretary to the African Section of the Society of Arts; a post he only resigned in consequence of failing health at the completion of the last session of the society.

For four years he served as one of the Board of Visitors of the Royal Institution, of which he became a member in 1876, subsequently being elected on the Council.

In 1878 he was elected a Fellow of the Royal College of Surgeons. Dr. Mann was well known in scientific circles, and for many years he was a member of the Astronomical, Meteorological, Geographical, and Photographic Societies.

From first to last he was a most active and indefatigable worker, and his end was probably hastened by his being, during the last four months of his life, when already in failing health, busily engaged in preparing and bringing out the catalogue of the Natal Court at the Colonial and Indian Exhibition. He was at the Natal Court engaged in this last work only three days before being suddenly struck down by paralysis, which terminated fatally two days afterwards, on August 4. He was buried at Kensal Green Cemetery.

He was elected a Fellow of the Society March 9, 1855.

James Pearson, M.A., vicar of Fleetwood, was born at Preston, Lancashire, and received his education there, up to the period of becoming an undergraduate of Cambridge University, first with Mr. Abbott, a highly reputed private schoolmaster of fifty years since, and afterwards at the Grammar School, chiefly under the mastership of the Rev. G. Nun Smith, an excellent teacher and proficient scholar. Here the foundation was laid for the distinguished college honours afterwards gained by the pupil. Whilst at the grammar school he took the second place for several years, and finally was bracketed as equal with the first, the two entering together upon their university career. Mr. Pearson came out as a first class in the examinations of his year at Trinity College, was subsequently rewarded with a scholarship, and graduated in the high position of fifteenth wrangler in 1848. After two years of further residence he accepted the curacy of the rural parish of Scarisbrick, near Ormskirk, a position, it may well be allowed, not very congenial to a man of his antecedents and abilities, and he resigned it to accept the dual appointment of rector of St. Edmund's and mathematical master of the King Edward the Sixth Grammar School at Norwich. After retaining this for about four years he was chosen one of the mathematical professors in the Royal Military College, Sandhurst. Either a longing to live near the

scenes of his childhood or a preference for parochial work, probably both combined, led him to forego this advantageous position for a second edition of the life of a country clergyman at Altcar, near Liverpool, a presentation of the Earl of Sefton. The population was a scattered one of three hundred souls, and the care and companionship of these was scarcely adequate to keep up the mental calibre in a man like Mr. Pearson, who was always full, even to excitement, of scientific instincts. Here, however, he found one or two congenial spirits and kindred tastes, whose friendship he held dear to the end of his days. Another change yet awaited him, and in 1862 he went to Workington as vicar of St. John's in that town, and remained nine years, quitting it in 1871 to go to Fleetwood. At Workington he was greatly appreciated both as a teacher and a preacher, and this appreciation was manifested in a high degree by a handsome testimonial presented on his leaving, and more handsomely impressed by the testimony to his worth in the words which accompanied the presentation.

His scientific researches, besides astronomy, went in the direction of the study of the tides, and on this subject he was a very frequent and constant contributor to scientific papers. His system of tide computation was adopted by the Admiralty for this coast, and he designed and had erected on the pier at Fleetwood a novel and ingenious contrivance for registering the height of the tides and testing his calculations, which were always found to be very accurate. He designed several novel contrivances in connection with this subject, one of which has been for some time erected on the Blackpool Pier and another at Fleetwood. It consists of a dial, which is set each day and points to the height of the tide at all hours during that day, both ebb and flow. He also published a Treatise on the Tides in 1881, which was hailed with much approval by many astronomers of the day, and very soon became scarce. Several works of a minor character on this and kindred subjects proceeded at different periods from his pen, all denoting the enthusiasm of the author for his favourite studies.

Mr. Pearson died on April 8, 1886, after a lingering and painful illness.

He was elected a Fellow of the Society April 10, 1874.

ADMIRAL SIR CHARLES FREDERICK ALEXANDER SHADWELL, K.C.B., F.R.S., was born on January 31, 1814, and was the fourth son of the late Right Hon. Sir Lancelot Shadwell, Vice-Chancellor of England. He entered the navy May 3, 1827, from the Royal Naval College, and passed his examination in 1833. On June 28, 1838, he obtained his lieutenant's commission, and was appointed in the following July to the *Castor*, Captain Edward Collier, with whom he served on the coast of Syria in 1840, and assisted at the operations against Caiffa, Jaffa, Tsour, and St. Jean d'Acre. His next appointment was

as first lieutenant of the *Fly*, in the East Indies, from December 1841 until June 1846, when he was promoted to be commander. In February 1850 he commanded the *Sphynx*, for service in the East Indies, and held this command through the Burmese War of 1851–1853, for his services in which he was on February 7, 1853, promoted to post rank, was gazetted to the Order of the Bath, and received the Burmese war medal with clasp. His next appointment was, in August 1856, to the *Highflyer*, which he commanded in the last war with China, taking part in the operations in the Canton River and in the capture of Canton, and being wounded in the attack on the forts at the mouth of the Peiho River in July 1859. For his services on this occasion Captain Shadwell was mentioned in despatches for "his valuable assistance." After the China War he was appointed to the *Aboukir*, which he commanded in the Channel and North America and West Indies in 1861 and 1862. His next appointment was that of flag-captain, in the *Hastings*, to Rear-Admiral Sir Lewis F. Jones at Queenstown, which he held till June 1864, when he was made Captain Superintendent of the Royal Haslar Hospital and of the Royal Clarence Victualling Yard. In this post he remained till he became Rear-Admiral in January 1869, vacating at the same time his appointment as Naval Aide-de-Camp to the Queen, which he had received in March 1866. He was commander-in-chief on the China station from 1871–1874. In 1873 he was gazetted a Knight Commander of the Bath, and in 1877 received the flag officers' pension for meritorious service. His last appointment was that of President of the Royal Naval College at Greenwich, which post he held from March 1878 till March 1881. He died at Meadowbank, Melksham, Wilts, on March 1, 1886.

In the year 1861 Sir Charles F. A. Shadwell was elected a Fellow of the Royal Society. He was the author of the following works:—"Formulæ of Navigation and Nautical Astronomy" (for the use of naval officers and students of nautical astronomy), "Tables for Facilitating the Approximate Prediction of Occultations and Eclipses," "Tables for Facilitating the Determination of the Latitude and Time at Sea by Observations of the Stars," "Tables for Facilitating the Reduction of Lunar Observations," "Notes on the Management of Chronometers and the Measurement of Meridian Distances," "Notes on Interpolation, Mathematical and Practical" (intended to form Ch. VI. of a work on navigation and nautical astronomy, which the author left incomplete at his death).

He was elected a Fellow of this Society on January 8, 1847.

David Smith was born at Selby, Yorkshire, in September 1821. He left school at the age of fourteen, and for about eighteen months was employed as a railway clerk, after which he was apprenticed to a carpenter and builder, and also studied for an architect and surveyor. In the year 1842 he went to

America, where he remained two years, travelling through the United States, and also the backwoods, collecting specimens of natural history, and at the same time earning his living by his trade of a carpenter, &c. Upon his return to England he went to Birmingham, and there spent the remainder of his life, the last twenty years of which he practised as an architect and surveyor. Always of a profoundly studious turn of mind, he early became deeply interested in the science of astronomy, and soon made himself conversant with that and other kindred physical sciences.

His meteorological observations were daily recorded, and published periodically in the local newspapers. In 1865 he was elected a member of the British Meteorological Society, and he had the honour of reading a paper before the British Association, at their meeting in Birmingham in 1865, on "The Meteorology of Birmingham," being the results of personal observations extending over a period of twelve years, viz. from 1853 to 1864 inclusive.

He was indefatigable in his efforts to spread scientific and useful knowledge amongst those around him, and by popular lectures, and the formation of science classes, he laid the foundation of that well-known and valuable establishment, the Bloomsbury Institution, where educational work is still carried on in connection with other useful agencies. As a public lecturer on astronomy, geology, meteorology, physiology, and various other subjects, Mr. Smith was deservedly popular, and his removal has caused a gap which it will be difficult to fill up.

His decease occurred after a short illness on December 23, 1885, and his loss is deeply felt and regretted by all who were connected with him.

He was elected a Fellow of this Society on June 13, 1862.

Edwin Story was educated at Shrewsbury School and St. John's College, Cambridge. He was a great lover of science, and became a member of the Linnæan, Geological, Historical, and Royal Geographical Societies. His favourite recreation from sterner mental study was the indulgence of poetical composition, particularly of classical poetry, in which he delighted and excelled.

Mr. Story was essentially of a retiring disposition; he led a studious and well-spent life, which was terminated by paralysis on February 1, 1886.

He was elected a Fellow of this Society November 8, 1867.

Charles George Talmage was born at Greenwich on November 12, 1840. He was educated at a proprietary school there, and afterwards studied mathematics under a private tutor.

Mr. Talmage commenced his astronomical career in the year 1856, at the Royal Observatory, Greenwich, where he remained for about four years. In 1860 he joined Mr. Hind as assistant

at Mr. Bishop's Observatory in the Regent's Park. At this time Mr. Talmage was in very delicate health, and it was considered necessary for him to sojourn in a warmer climate; he therefore was compelled to leave Mr. Bishop's Observatory, and subsequently accepted an appointment as private secretary to the late Mr. R. Coventry, who was then residing at Nice. There Mr. Talmage devoted himself to double star observations, and undertook a re-examination of Admiral Smyth's Bedford Catalogue. Four years' residence in the south of France so far restored him to health as to enable him to return to England, where he again joined Mr. Hind for a short time at the Observatory, which Mr. Bishop had removed from the Regent's Park to Twickenham.

In 1865 Mr. Talmage was appointed Director of the private Observatory of Mr. J. Gurney Barclay at Leyton, which appointment he held up to the time of his death. Here he devoted the fine 10-inch Cooke refractor almost exclusively to double star work. Most of his excellent observations have been published in the volumes of the "Leyton Astronomical Observations," and others will be found in the volumes of the *Monthly Notices*. (It is to be regretted that with Mr. Talmage's death the work of the Leyton Observatory has closed, as Mr. Barclay has since then presented the large equatoreal to the Radcliffe Observatory, Oxford, and the Transit circle to the Oxford University Observatory.)

In 1870 Mr. Talmage went out in the "Urgent" to Gibraltar to observe the Total Solar Eclipse of that year, his duty being to take angular measurements of *Saturn* if seen through the corona, but the unpropitious weather on the day of the eclipse prevented any observation being made. In 1882 he was appointed by the Government as officer in charge of the West Indian expedition for observing the Transit of *Venus*. He was located at Barbadoes, in company with Lieut. Thomson, R.A., where he was fortunate in securing good observations of all contacts both at ingress and egress.

Mr. Talmage was for many years a member of the British Association, and regularly attended their meetings. Besides being an able microscopist, he had no mean knowledge of medicine and botany.

In the locality in which he lived Mr. Talmage was both respected and beloved. His hearty, genial, and kind disposition made him numerous friends whithersoever he went. Ever ready to afford to others all the help that was in his power, and with a happy ungrudging manner which made him deeply esteemed, it is no wonder that his untimely death has caused a wide-spread feeling of regret among those who knew him. He was taken seriously ill on February 23, 1886, and, after much suffering, died on March 20.

A memorial to him has been erected by his many friends in the church of St. Michael and All Angels, Walthamstow.

He was elected a Fellow of the Society Dec. 11, 1863.

William Tomlinson, Junior, was born at York about forty-five years ago, where he received his education at St. Peter's School, in which his father held the position of mathematical master. About twenty years ago he went out to New Zealand to Bishop Abraham, of Wellington, with the intention of taking holy orders. From Wellington he proceeded to Wanganui, and there, feeling that the teaching profession was the vocation of his life, he entered upon its duties with all the zeal of his enthusiastic nature as assistant master in the school conducted by Mr. Goodwin. While in Wanganui it may be mentioned that the Maori War was raging, and during that troublous time Mr. Tomlinson belonged to a local cavalry corps, took part in some engagements with the natives, and was rewarded with a New Zealand war medal. Subsequently he was appointed to the position of assistant master at the Nelson College, where he remained until 1873, when he received the appointment at the Auckland College and Grammar School, which he held at the time of his death. During his residence at Nelson he married a daughter of the late Mr. Samuel Kingdon. Mr. Tomlinson was of very scholarly habits, and in 1883, notwithstanding the demands upon his time by his professional duties, he succeeded in obtaining the B.A. degree in connection with the New Zealand University. He was a diligent student of astronomy himself, and encouraged the study of it in no small degree in others. He took a creditable degree in the University of New Zealand, in which astronomy was a subject of examination, and he gained considerable repute by his writings on educational matters, and was also distinguished as a public teacher and private coach; but his onerous duties, and the exigencies of a large family, did not allow him to carry out the practical views which his sound mathematical knowledge would have enabled him to do; but at the time of his death he was looking forward with a lively hope to a time when more leisure, less onerous duties, and easier circumstances would have enabled him to do good service to practical astronomy.

His success as a teacher must be attributed to his enthusiasm for his profession. He always felt that the imparting of knowledge was comparatively a small part of a schoolmaster's work, and that the development of a manly and upright character in each of his pupils was his highest aim. In fact, he wished to make them gentlemen in the true sense of the term, and his own demeanour and bearing towards his pupils were the most powerful factors in producing this result. His genial disposition and active habits led him to take the deepest interest in the doings of his pupils in the playground, and he naturally became a great favourite with them. His interest in his pupils did not cease when they left school to enter upon business pursuits, and he always manifested a great concern for their welfare, and was ever ready to assist those who desired to further pursue their scholastic studies.

Mr. Tomlinson's death took place under exceptionally lamentable circumstances. On the morning of January 21, 1886, he went out with a double-barrelled gun, intending to shoot gulls. He was accompanied by his eldest son, aged eleven, and in climbing up a hill in the Wakapuaka Road, he slipped, when the gun exploded and the shot from the charge went through his heart. He has left to mourn his loss a widow and a family of five children.

He was elected a Fellow of the Society April 9, 1873.

Professor Theodor von Oppolzer, the only son of the celebrated physician Dr. Johann von Oppolzer, was born at Prague, October 26, 1841. His early years were spent at Leipzig, whence, while yet in his childhood, he moved to Vienna, as his father had been appointed professor at the university of that city. Here he studied physics, but his abilities and great predilection for mathematics induced him to devote all his spare time to the study of natural philosophy. In these studies he was aided by Dr. E. Weiss, the present Director of the Vienna Observatory, who soon recognised his eminent talents for Astronomy, and encouraged him to devote his life to that science. Oppolzer, who was possessed of independent means, sufficient to remove all necessity for seeking immediate employment, therefore constructed a well-appointed observatory after he had taken the degree of a Doctor of Physics. At this observatory he observed asteroids and comets during the years 1862 to 1872 with great zeal, and his computations of the orbits of such bodies were the first papers by which he introduced himself to the astronomical world. For such work he was especially qualified by the quickness and certainty with which he conducted extended numerical computations. He published numerous papers on this subject.

He also published all his valuable theoretical researches in this branch of Astronomy in an excellent "Lehrbuch zur Bahnbestimmung der Kometen und Planeten," of which the first volume appeared 1870; and in a second, totally revised and much enlarged edition, 1882. The second volume was published in 1880. In this classic work the author has in fact reconstructed on a more comprehensive plan the *Theoria Motus* of Gauss. The theories upon which the calculation of the orbits of comets and planets depend are discussed so fully and exhaustively, that the work forms, indeed, a Treatise on Astronomy, "not only useful to the practical Astronomer, but of the highest value to the Mathematician who desires to know the exact manner in which the dynamical formulæ he is acquainted with are actually applied in practice to the calculation of orbits." This most important work has been recently translated into French by Prof. Ernest Pasquier, of Louvain.

In the year 1873 Prof. Oppolzer was entrusted by the Austrian Government with the astronomical work for the *Europäische Gradmessung.* In this position, which he held till his death,

being in his last years chairman of the Austrian Commission of the *Europäische Gradmessung*, he showed an extraordinary ability as an organiser, and executed a long series of telegraphic longitude operations between various cities of Austria amongst each other, and with the capitals of other countries. For many weeks in the summer of 1876 operations were undertaken at the Royal Observatory, Greenwich, by Professor Oppolzer's assistants for the purpose of making the time observations and telegraphic observations necessary for determining the longitudes of Vienna and Berlin, connected also in some measure with Munich and Paris. All the observations for this very extensive work are finished, but unfortunately the reductions are not very far advanced. In connection with these investigations he also conducted a series of pendulum experiments for determining the intensity of gravity at Vienna, and he made a very interesting and important study of the vibrations of the stand of the pendulum and their influence on the time of its oscillation. But here also his very premature death prevented him from discussing more than a small part of these extremely delicate researches, for which he devised special methods of observation and reduction.

In the year 1881 Oppolzer published "Syzygien-Tafeln für den Mond," which were intended to supply a simple and convenient means of finding very approximately the time of New and Full Moon, particularly in the case of an ecliptic syzygy, and of calculating all the circumstances of an eclipse without the necessity of having recourse to the Solar and Lunar Tables.

But the most important work undertaken by Oppolzer is his "Canon der Finsternisse" [Table of eclipses], which will be found to be an invaluable basis for all historical researches connected with solar eclipses, and will form an enduring monument of the power of its author.

This masterly paper contains not only the elements of eclipses of the Sun, but also of those of the Moon from 1207 B.C. to 2162 A.D. The elements are given for all the eclipses partial and central occurring during this period of time.

The tables furnish the computations of 8,000 Solar Eclipses, of which about 2,220 are total, 355 annular and total, 2,605 annular, and 2,820 partial.

Of the Moon, 5,200 eclipses are computed; for which the tables give not only the date, but also the magnitude, the time of the middle of the eclipse, and the geographical position of the point on the earth where the Moon at that moment is at the zenith.

Appended to the work are 160 charts, in which is laid down the central line of all Solar Eclipses visible in the northern hemisphere, and as far as 30° south latitude. Partial eclipses of the Sun, and those which are central only in regions more south than 30° are not mapped.

The work forms vol. lii. of the *Memoirs of the Imperial Academy of Sciences* at Vienna.

This noble undertaking Oppolzer was only just able to bring to a conclusion, for it was but a few hours before his death that he read the last proof-sheets of it.

Besides all this, Oppolzer was engaged during the last years of his life in researches on planetary disturbances, especially on the theory of the motion of the Moon, on astronomical refractions, and on the resisting medium, &c.

From this brief record of his more important researches it will readily be understood that his life was one of constant work, and that he was enabled to perform all he did only by an indefatigable diligence, a very remarkable power of memory, quickness of perception, and intuitive grasp of whatever he studied.

Von Oppolzer was appointed in 1876 Professor of Astronomy at the University of Vienna, and received besides this, various other distinctions from the Austrian Government and several foreign sovereigns. He was also Member of the Imperial Academy of Sciences at Vienna, Honorary Member of the Royal Academy at Munich, Correspondent of the Institute of France, and Fellow of many other scientific bodies. He was elected an Associate of the Royal Astronomical Society on Jan. 9, 1874.

In the middle of November 1886 Oppolzer returned to Vienna somewhat ill, after attending the Paris International Conference on Weights and Measures, and the meeting of the Permanent Commission of the *Europäische Gradmessung* at Berlin. No one would have considered, however, from his appearance, that his end was so near. At first his illness was thought to be a kind of malaria, but it very soon proved a serious disease of the heart, of which he suddenly died, on the morning of December 26, at the early age of 45 years.

E. W.

## Proceedings of Observatories.

The following Reports of the proceedings of Observatories during the past year have been received by the Council from the Directors of the several Observatories, who are alone responsible for the same.

### *Royal Observatory, Greenwich.*

During the past year the meridian work at this Observatory has been sensibly increased by the efforts made to complete the forthcoming Ten Year Catalogue of Stars (1877–1886) as far as possible, both by securing places of nearly all stars down to the sixth magnitude inclusive, not observed at Greenwich since 1860, and by obtaining at least three observations of each star. Thus the total number of meridian transits for 1886 is 6,417, and of meridian zenith distances 6,219; the numbers for the month of December alone, when special efforts were made, being 1,133 and 1,093 respectively. The number of stars observed during 1886 is 1,666. At the same time the stellar work has not been allowed to interfere with the regular observations of Sun, Moon, and planets, and the general work in other respects has been rather heavier than in previous years. The proper motions in use have been carefully revised and compared with those of Auwers; and, in the case of clock stars, a further comparison has been made with the last ten years of Greenwich observations, from which it is clear that Auwers' proper motions may be advantageously adopted throughout. They will accordingly be used regularly from January 1, 1887, and also in the formation of the Ten Year Catalogue. As a preliminary to this, the application of proper motion for fraction of the year has been thoroughly examined for every observation in the period 1877–1886, and corrections applied where, as occasionally happened, different proper motions had been used in the same year. Preparations have been made to apply corrections for reduction to Auwers' proper motions, and for reduction to the same R—D correction throughout in the computations for the Ten Year Catalogue.

A considerable amount of information has been obtained as regards personality in observation, both as depending upon

direction of measurement or motion, and on the differences between the chronographic and the eye-and-ear method of observing. The reversion prism has been used to observe about 200 transits of clock stars and 200 of polar stars with the transit-circle, and about 550 of the Moon and stars with the altazimuth, more than 200 of these latter being observed by eye and ear. As a general result, it appears that there is in no case any sensible personality depending on the direction of measurement, and that the personality depending on the direction of motion is in every instance very small for clock stars, and insensible for slow-moving polar stars. For the regular observers the eye-and-ear personal equations differ but little from the chronographic, except in one instance, where the difference amounts to as much as $0^{s}\cdot6$. From observations made with the personal equation machine, which has been found to work satisfactorily, and to give results in accordance with those deduced from observations of clock stars, it would appear that all the observers observe too late. Further observations are, however, required to determine the absolute personal equations with certainty. With a view to obtaining a register of the end as well as the beginning of the contacts made by the personal equation machine, a small chronograph, by Krille, made many years ago for mechanical registration, is being adapted by Messrs. E. Dent & Co. to electric registration of make-and-break contacts.

The mean error in R.A. of Hansen's Lunar Tables with Prof. Newcomb's corrections is $+0^{s}\cdot029$ for the year 1886, as deduced from ninety-six observations with the transit-circle; for the years 1883, 1884, 1885, the corresponding quantities were respectively $+0^{s}\cdot032$, $+0^{s}\cdot021$, and $+0^{s}\cdot028$.

Four determinations of flexure of the transit-circle in 1886 gave results $+0''\cdot15$, $+0''\cdot42$, $-0''\cdot16$, and $+0''\cdot13$.

The apparent correction to the nadir observation, deduced from reflexion observations of stars in 1886, is $-0''\cdot09$, the results for individual months showing considerable fluctuations. In comparing this with results for previous years, it is to be remarked that new steel screws were applied to the microscope micrometers on January 1, 1886. It is considered that no correction is now required to the nadir observation.

Experiments on the effect of the limitation of aperture when observations are taken through the central cube of the transit-circle having led to the suspicion that the object-glasses of the collimators might be defective, they have been examined by Mr. Simms, who has reported that they are excellent.

The altazimuth observations of the Moon in the first and last quarters have been regularly continued as before.

Further additions have been made to the Lassell Equatorial, with a view to adapting it to stellar photography. With this object the Corbett Refractor of 6½ inches aperture has been mounted on the cradle of the Lassell telescope, so that the position of the compound instrument can be very conveniently

watched by an observer. Slow motion in R.A. with differential wheels, and an improved clamp and slow motion in N.P.D. are being added. A circular camera to carry plates of $8\frac{1}{4}$ inches diameter has been mounted at the principal focus, but no photographs have yet been taken.

Progress has been made in the construction of the new 28-inch refractor. A satisfactory flint-glass disc has been produced by Messrs. Chance, and M. Feil of Paris has undertaken to supply the crown disc. The details of the special tube have been finally settled, and Mr. Grubb is engaged on its construction.

Comet *d* 1885 (Fabry) has been observed on five nights with one or other of the equatorials; Comet *e* 1885 (Barnard) on nine nights; Comet *a* 1886 (Brooks) on six nights, and Comet *f* 1886 (Barnard) on twelve nights. Twenty-four occultations of stars by the Moon have been observed, in five cases by two observers, in one by three observers, and in two by four observers; and forty phenomena of *Jupiter's* satellites, with one or other of the equatorials.

Owing to the pressure of the Sun-spot work and the absence of Mr. Maunder in the summer for observation of the solar eclipse in Grenada, the chromosphere has only been examined on eight days. With respect to measures of the displacements of lines in stellar spectra, 283 comparisons of the F line, and 30 of the *b* lines have been made, the number of stars examined being 54. The displacements of the *b* and F lines in the spectra of *Venus* and *Mars* have also been measured, 20 observations having been made on *Venus* and 19 on *Mars*; while 94 comparisons of the *b* or F lines in the spectrum of the Moon or of the sky have been made for general check on the accuracy of the results; and 5 measures have been obtained of the relative motion of the limbs of *Jupiter*.

The spectra of Mr. Gore's new star in Orion, of 51 Schjellerup, and of Comets *e* 1885 (Barnard) and *f* 1886 (Barnard), have also been examined. Photographs of the Sun, 420 in all, have been taken on 209 days, and these have been supplemented by photographs taken at Dehra Dûn, in India, and at the Royal Alfred Observatory, in Mauritius; so that in the year ending Oct. 31, 1886, there are only 5 days on which no photograph is as yet available for measurement. A very marked decrease in the number of spots is noticeable in 1886, especially in the last six months; indeed, since the middle of September, the Sun has been almost free from spots.

The magnetical and meteorological observations have been carried on on the same lines as in previous years, and the observations of the principal meteor-showers have been continued.

The arrangements for trials of chronometers and deck watches have engaged much attention during the past year, and the business connected with chronometers generally has pressed heavily on the Observatory. One of the clocks returned from

the Transit of *Venus* Expedition (1874), has been fitted up at Devonport, under Capt. Wharton's directions, to give time signals to the port. This clock is adapted to give hourly signals (by the collapsing of a cone or drum), and is corrected daily by the help of a time signal from Greenwich at 10 A.M., which automatically starts an auxiliary seconds' pendulum, suspended freely just behind the clock pendulum. The attendant then accelerates or retards his clock pendulum by electro-magnetic action, so as to synchronize it with the free pendulum, indicating Greenwich mean time. Preliminary trials of the clock were made at Greenwich last summer, and it has been in successful action since December 1, a return-signal to Greenwich, sent automatically by the Devonport clock at $1^h\ 0^m\ 39^s$ P.M., giving evidence of the accuracy with which the clock has been corrected.

The volume of Greenwich Observations for 1884, and the separate copies of results, were distributed last October, and the printing of the volume for 1885 is nearly complete. In an appendix to the Greenwich Observations, is given a series of diagrams representing the diurnal change in magnitude and direction of the magnetic horizontal force for each month of the years 1841 to 1876, by Sir G. B. Airy, K.C.B., late Astronomer Royal.

Two members of the staff of this Observatory, Mr. Turner and Mr. Maunder, took part in the expedition to Grenada, West Indies, to observe the total solar eclipse of 1886, August 29.

## *Armagh Observatory.*

The micrometrical observations of nebulæ have been continued with the 10-inch refractor, but during the greater part of the year the weather was very unfavourable for faint objects. The nebulæ on the working list are chiefly such as have not yet been observed with wire micrometers. A great deal of time has been spent in reducing to the epoch of 1860 all the positions of nebulæ published during the last ten years, with a view to the compilation of a new General Catalogue of nebulæ and clusters.

The Second Armagh Catalogue of 3,300 stars was distributed in August last.

## *Cambridge Observatory.*

The zone stars are nearly all now observed, and the reductions are steadily progressing.

The total number of observations of stars made with the Meridian Circle during the year is 2,252; of these 651 were of clock stars, 70 of *Polaris* above the pole, involving 152 circle

readings, and the same number below the pole with 169 circle readings; the remaining 1,461 observations were of zone stars.

The Nadir point and level were observed 202 times, the line of collimation 200 times.

The entire number of observations of zone stars, since the commencement, now amounts to 43,576.

The Mean Right Ascensions at the epoch (1875·0) are determined up to July 12, 1877; the Mean Right Ascensions January 1·0 of each year up to the end of 1881; and the True Right Ascensions to September 30, 1886.

The North Polar Distances are reduced to the epoch up to March 16, 1878; the Mean North Polar Distances for January 1·0 of each year to the end of 1881; and the True to November 25, 1886.

511 observations of standard stars made by Mr. Graham in 1885 give $+0''·55$ for the mean reduction to the standard Berlin places in North Polar Distance, without making any allowance for flexure or errors of division; 82 observations by Miss Walker, nearly all taken by daylight, gave $+1''·18$. The North Polar Distance was, as in former years, deduced from the observed Nadir point, and the assumed colatitude $37° 47' 8''·4$.

60 observations of *Polaris* above pole, corrected for flexure and errors of division give, for reduction to Berlin N.P.D., $+0''·45$; while 59 observations below pole, similarly corrected, give $-0''·33$. These give for the reduction of Cambridge to Berlin N.P.D. for *Polaris* $+0''·06$, and for correction of assumed colatitude $+0''·39$.

It may be interesting to compare the colatitudes obtained from *Polaris* and observed Nadir Point for the last eight years.

| | ° | ′ | ″ |
|---|---|---|---|
| 1878 . . | 37 | 47 | 8·86 |
| 1879 . . | | | 8·98 |
| 1880 . . | | | 8·815 |
| 1881 . . | | | 8·755 |
| 1882 . . | | | 8·85 |
| 1883 . . | | | 8·825 |
| 1884 . . | | | 8·96 |
| 1885 . . | | | 8·79 |
| Mean . . | 37 | 47 | 8·854 |

*Polaris* was observed directly and by reflection on April 8; the coefficient of correction for level thence deduced is $b = -0^s·337$, the coefficient obtained on the same day by means of the collimators and the reflection of the wires is $b = -0^s·335$; the unit in each case being $15''$ of arc.

On May 12, 1886, we furnished Dr. Gustaf Ericsson, of Upsala, with the places for 1875·0 of four of our zone stars which had

been compared with the Comet 1863 III., and on November 24 we likewise supplied Mr. Bidschof of Vienna with the places for 1875·0 of nine of the zone stars which had been compared with one or other of the Comets 1848 I. and 1849 III.

### *Dunsink Observatory.*

During the early part of the year the Meridian Circle was employed, along with the chronograph, for observing stars with large proper motion, taken chiefly from the sources mentioned in last year's Report. From the middle of February, however, up till September, the observation of these stars was frequently interrupted for the purpose of completing the list of southern stars referred to in former Reports. The work of filling up the gaps still remaining in this list necessarily occasioned long delays at the telescope, so that the number of observations this year will compare unfavourably with that in former years.

The latter months of the year, from September to December, were almost entirely occupied with the work of preparing for the press the Sixth Part of the Dunsink Observations, which will contain the observations of the southern stars which were commenced by Dr. Dreyer in 1882. This work is now in the hands of the printer, and will shortly be published.

The number of Right Ascensions observed was 506, and of Declinations 295, besides observations of standard stars for the time service to Dublin.

In addition to the usual observations of Right Ascension and Declination, a large number of measures were made in January, February, and December for determining the periodic errors of the microscope screws. The corrections were found to be of the same general character, but smaller than at the last determination.

For the purpose of determining the difference of the radii of the pivots of the Meridian Circle a large number of levellings have been made in both positions of the instrument. They show that the correction for this irregularity is small, but its exact value has not been deduced, as the series of observations is not yet complete.

The results of the observations of the occultation of *Aldebaran* on January 16 which were made at this Observatory have been published in the *Monthly Notices* for February.

Records of the velocity and direction of the wind have been taken as usual throughout the year.

### *Royal Observatory, Edinburgh.*

Through the past twelve months, transit observations for sidereal time, and electrical exhibitions of mean solar time computed for Greenwich, and given to the public by means of

time-ball, time-gun, and controlled clocks, have been kept up daily.

The bi-diurnal meteorological observations at 55 stations of the Scottish Meteorological Society have been computed, condensed, and described, partly every month and wholly every quarter, for the Registrar-General of Births, Deaths, &c., in Scotland, in whose printed returns for months and quarters they have accordingly appeared.

During the past autumn the printing of the "Edinburgh Catalogue, Discussion, and Ephemeris of Stars" was completed, published, and distributed in the usual manner as one thick volume, numbered XV. of the Observatory series; and MSS. chiefly spectroscopic are now being prepared for a proposed volume XVI.

A paper has been also written by the Astronomer descriptive of his proposed new method for finishing the Equatorial of the Edinburgh Observatory; but it is kept in abeyance until the scheme of the Government Committee of 1879 shall have been either carried out or given up by those charged with its execution.

*The Kew Observatory of the Royal Society, Richmond.*

The Sun-spots were delineated and numbered after Schwabe's method, as usual, on 169 days during the past year.

Three hundred and nine observations of solar and sixty-one of sidereal transits have been taken, for the purpose of keeping correct local time at the Observatory, and the clocks and chronometers have also been compared daily.

At the request of General Walker, F.R.S., certain experiments were made with the view of determining the stability of the Experimental House as a site for pendulum operations. These having proved that building unsuitable, a wooden erection of convenient dimensions has been constructed, at the desire of the Pendulum Committee of the Royal Society, in the lower South Hall of the Observatory, on the spot occupied in 1873 by Captain Heaviside, R.E., when experimenting with the Russian pendulum.

In this room the Indian Pendulum Apparatus, recently returned by Professor Pierce from the United States, has been erected, in order to repeat the observations made by Colonel Herschel, R.E., in 1881, Captain Heaviside in 1873, and Captain Basevi in 1865. Eventually, it is intended to convey the whole to Greenwich, and at the Royal Observatory another series of observations and experiments will be conducted.

The usual magnetical and meteorological observations and reductions, and also the verification of instruments, operations to which the attention of the Observatory is mainly directed, have been carried on as formerly.

*Liverpool Observatory, Bidston, Birkenhead.*

Careful attention has been given to transit observations of stars for the determination of clock errors. The two sidereal clocks have been compared daily with the normal mean-time clocks, and duplicate comparisons of all the chronometers with the latter have been made daily as heretofore. Greenwich mean time has been communicated to the Port daily, Sundays excepted, by means of the time-gun placed on the Morpeth Dock Pier-Head. No instance in which the gun has failed to fire has occurred during the past year, and the flash has in each case accurately indicated 1 P.M. as shown by the normal clock in the chronometer room. Two hundred and twenty-seven chronometers have been tested during the past year. When the test certificate shows the performance to be unsatisfactory, it is the general practice for the maker to examine and adjust the instrument, and return it to the Observatory to be re-tested. An important service is thus rendered to shipowners and ship-masters by preventing defective and imperfectly-adjusted chronometers being taken to sea. The records received during the past year of the performance at sea of the Pacific Steam Navigation Company's chronometers show that, using the rates corrected for temperature supplied from this Observatory, the average error of longitude by chronometer for an average voyage of 101 days was about four miles.

No alteration has been made in the meteorological work. No interruption has occurred in the records of the self-registering instruments and the daily, weekly, fortnightly, and monthly Reports have been furnished as in previous years.

*Radcliffe Observatory, Oxford.*

The following have been the subjects of observation during the year 1886:—

With the Transit Circle:—

1. Observations of stars to the seventh magnitude inclusive between 115° N.P.D. and the Equator.

2. Observations of the Moon, which are continued throughout the lunation, and regularly compared with the Right Ascensions and North Polar Distances of Hansen's Lunar Tables. Such comparisons have been generally discontinued at other Observatories; and these results, therefore, appear to have a special value in keeping distinctly before astronomers the extraordinary

character of the change between the results of observation and theory which took place about the year 1864. The mean error in longitude of Hansen's Tables has changed from $-1''\cdot61$ in the year 1863·5 to $+15''\cdot34$ in the year 1886·5, being at the average rate of $0''\cdot74$ per annum.

3. Observations of the Sun.
4. Reflexion observations of stars.

The following table gives the number of observations made during the year 1886:—

Transits, 2,812.
Circle observations, 2,663.

These totals include—

Observations of the Moon on 49 days.
Observations of the Sun on 76 days.
23 Reflexion observations of stars.
365 Determinations of Nadir point.
2 Durations of passage of the Moon's diameter.
2 Vertical diameters of the Moon.

With the extra-meridional instruments:—

13 observations of 9 occultations of stars by the Moon.

The volume for 1883 has been printed and distributed.
The volume for 1884 is being prepared for press.
The observations made in 1885 and 1886 are completely reduced.

A well-mounted Equatorial by Cooke with an exquisite object-glass of ten inches aperture has been presented to the Observatory by J. Gurney Barclay, Esq. The building for the reception of the instrument has been prepared from designs kindly furnished by Mr. Common, but the continuance of the late severe frost has delayed the arrival and mounting of the instrument.

### *Oxford University Observatory.*

The work of this Observatory has been necessarily confined during the past year to a research as to whether the new process of Astronomical Photography is or is not practically applicable to the most delicate of astronomical investigations, such, for instance, as the determination of Stellar Parallax. The reply is unmistakably in the affirmative, inasmuch as the Parallax of $61^1$ and $61^2$ *Cygni* has been obtained in reference to no less than four comparison stars, with singularly accordant results. The preliminary particulars have been communicated to the Royal Society and the Royal Astronomical Society.

The attention of the Observatory staff has also been directed to the mounting, renovation, and electric lighting of the excellent Transit Circle presented to the Observatory by Mr. J. G. Barclay.

### *Temple Observatory, Rugby.*

This Observatory has been opened on seventy-six evenings during the year, on most of which there has been the usual attendance of members of the School, when the usual instruction has been given.

Mr. Seabroke has given the whole of his spare time to the measurement of the motion of stars in the line of sight with the spectroscope on the Reflector, and 100 sets of measures have been made.

The results of the last few years have been reduced and lately brought before the notice of the Society.

Mr. Percy Smith has continued the work of measuring the position and distance of double stars, and has been doing clerical work in connection therewith. He has also arranged all our star forms for future re-observation.

### *Stonyhurst College Observatory.*

The solar work continues to receive the same attention as in previous years. The Sun was observed on 235 days, and 224 drawings were made of the whole disk, including spots and faculæ.

Whenever the definition was particularly good the general surface of the Sun has been studied in conjunction with Janssen's excellent photographs, and continual change is seen everywhere.

The measures of the chromosphere and prominences have been more successful than in any other years, 101 complete observations and two partial ones being recorded.

The spectra of Sun-spots were examined on 21 days, and on six of these occasions spot bands were visible. The lines most widened this year were generally the ordinary solar lines, which was far from being the case during the maximum period.

A new class of solar observations has been added to the routine work this year, the direction of the flames of the chromosphere being noted with a wide tangential slit. As these observations require a very perfect sky, and are only made when the others are completed, they are entered only on 21 days.

Positions of the comets of Fabry, Brooks, Barnard, and

Finlay have been determined, and the usual watch kept for the phenomena of *Jupiter's* satellites and for lunar occultations.

In preparation for the total solar eclipse of August 29, a $5\frac{1}{2}$-inch object-glass by Alvan Clark and a powerful direct-vision spectroscope by Hilger were purchased by the college authorities.

### *Mr. Common's Observatory, Ealing.*

The last year has been entirely devoted to the construction of the 5-foot reflector. The machine for grinding was completed in September, and great progress has been made with the mirror. Photography has been used to obtain permanent records of the state of the surface by using the reflected light from a pinhole (illuminated by a lamp), as in the system of testing used by Foucault. It is found that so small a quantity of light as can come through a hole ·004 inch placed at the centre of curvature can be photographed in a few seconds after reflection from the surface.

A series of photographs have been taken from the first rough polish to the present state, and will be continued.

The kind of mounting has been determined upon, and the heavy work put in hand. It is hoped that the whole may now be completed without further delay.

The telescope is to be devoted to photography, and the mounting has been designed to give the greatest amount of steadiness and perfection of movement.

### *The Earl of Crawford's Observatory, Dunecht.*

Early in the year Dr. L. Becker concluded the determination of the latitude by prime vertical observations begun in 1885. This involved an exact examination of the pivots with the level, which proved particularly interesting, as it could be made in both the pairs of Y's with which the instrument is provided. The maximum error is $0''\cdot66$, corresponding to 0·00006 inch; but only a small fraction of this affects the telescope when near the zenith. The general figure of the axis comes out the same when rotated in the meridional bearings, as in those for the prime vertical. The observations are all reduced.

In the moonless nights of the autumn Dr. Becker turned the large aperture of the Transit Circle to account by observing nebulæ; in this way ninety-six places have been secured in seventeen nights. The bright nights were devoted to comparison stars and to a complete re-determination of the positions of the

*Durchmusterung* stars within 1° of the pole. This latter work is carried on with bright-field illumination. Observing was commenced on eighty-three nights, but on only forty-five of these did the clouds permit of fairly continuous work.

During the past year the 15-inch Equatorial has been used almost solely for spectroscopic observations. A few measures of double stars or of faint stars in the Great Nebula in *Andromeda*, or near Mr. Gore's variable star in *Orion*, were taken when the spectroscope was dismounted.

The large star spectroscope mentioned in former Reports was punctually finished by Messrs. T. Cooke and Sons in March. It works well in all respects. The single flint prism of 60° supplied with the instrument defines so well, that, with a dispersion of only 5° 7′ from A to H, it separates the pair of lines $488{\cdot}81^{mmm}$ and $488{\cdot}84^{mmm}$, and shows forty-three lines between B and C. All three lines in the ring nebula in *Lyra* can be measured without difficulty. A prism of 20° refracting angle, by Merz, promises to be very useful for faint stars, while a large compound prism by Mr. Grubb gives about as much dispersion as even the brighter stars will satisfactorily bear.

The solar spectrum was measured on twenty-one days to obtain data for reducing observations of other spectra. A very pliable formula with three coefficients devised by Dr. Becker represents the minimum deviations from A to H for the 60° prism to within about 20″, leaving outstanding errors that can be dealt with graphically.

Owing to its unfavourable position Brooks' first comet was only observed once with the large spectroscope, but both it and Fabry's comet were observed three times with a smaller instrument. Barnard's October comet was examined on eight occasions with the new spectroscope, and was photographed on the 16th, 17th, and 26th December with a 4-inch lens. The two earlier photographs show the lateral tail.

Twenty-three circulars were issued in the year, all dealing with comets, with the addition of two notes on *Jupiter's* fourth satellite. Observers are again largely indebted to Dr. H. Oppenheim for elements and ephemerides of comets.

Comet Brooks (2) of 1885 could not be found on March 9 and 11 by Dr. Becker, although the ephemeris afforded some hope that it might be visible.

The weekly time-gun and the meteorological observations have been continued as usual.

The maximum and minimum thermometers were stolen on August 2.

### *Mr. Edward Crossley's Observatory, Bermerside, Halifax.*

The observations made in 1886 were similar to those in previous years. Of the satellite phenomena of *Saturn* thirteen observations were obtained, and ten of those of *Jupiter.* Some 180 measures with the wedge photometer were made, and forty stars observed with the Transit Circle for time. The 3-ft. Reflector has taken up a good deal of time. The dome for this instrument is now complete: it can be moved round once in five minutes or once in twenty-four hours by a water-engine with two speeds. The observing platform and gallery are suspended from the dome, and therefore the observer moves with the dome. The opening is 6 feet wide from top to bottom, and extends from the horizon to 3 feet beyond the zenith. The shutter is in two pieces, which move horizontally; and one handle opens and closes both in about one minute. The Reflector is now in good working order, and the clock drives well. The mirror will soon need re-silvering, as it has been much exposed to damp, &c., during the erection of the Observatory.

### *Mr. C. E. Peek's Observatory, Lyme Regis.*

The equatorial (of $6\frac{4}{10}$ inches aperture) has been employed in the systematic observation of variable stars from a selected list: 146 nights were suitable for observation. Transit observations for time have been taken on all available nights. The most cloudy month was February; the clearest, December.

### *The Earl of Rosse's Observatory, Birr Castle.*

During the year 1886 some experiments have been carried on at intervals with a view of increasing the accuracy of the apparatus for measuring Lunar Radiant Heat, but they are still only in progress.

Some photographs of the Moon were taken towards the close of the year. Several are of average good quality, and show in every case, and especially with the longer exposures, a decided advantage from the electric control of the driving clock, which had not been applied at the time when the last photographs were taken. In attempts to photograph the Great Nebula in *Orion*, however, the tilting of the speculum upon its supports

during the prolonged exposure still causes serious difficulty. No hand-correction has been as yet resorted to.

About eighty sketches of the planet *Jupiter*, which have accumulated since the last series was published, are awaiting publication when some decision as to the best mode of reproducing them shall have been arrived at.

Dr. Boeddicker has, during a considerable number of nights, been engaged upon an eye-sketch of all the Milky Way, so far as it can be satisfactorily reached in this latitude, and he hopes to represent it in more minute detail than has hitherto been done.

Meteorological observations have been carried on as usual.

### *Colonel Tomline's Observatory.*

The work at this Observatory has suffered some interruption owing to the illness of the observer, but it is now again fully resumed. The observation of comets continues, as for some years past, to be the principal work to which the instrumental means are devoted, as it also appears to be that for which they are best fitted. Progress has been made in the reduction of previous observations, and two communications containing results of observations have been made to the *Astronomische Nachrichten* within the past year. They will be found in Nos. 2,723 and 2,754, and comprise observations of Comets 1884 III. Wolf, 1885 I. Encke's, 1885 II. Barnard, 1886 I. Fabry, 1886 II. Barnard, and 1886 V. Brooks I. At the time of the latter publication the whole of the cometary work at this Observatory had been reduced and published. Subsequently satisfactory series of observations have been made of comets Barnard-Hartwig and Finlay: the former having been observed on twenty and the latter on fifteen occasions, while both series are at the end of the year still incomplete. Efforts will be made to publish these at an early date, and thus avoid the accumulation of arrears in future.

### *Lieutenant-Colonel Tupman's Observatory, Harrow.*

The Meridian Circle has been employed in the determination of the places of comparison stars and stars which have been occulted by the Moon. Five hundred and fifty observations of both elements have been obtained, about one-third of which are of fundamental stars. The errors of division of the circle have not been investigated; and the Nadir observation being generally difficult, owing to the vibrations of the soil, the Declinations of stars are determined by comparing them with the fundamental stars, on

the same principle as is customary for Right Ascensions. All the star observations are reduced to the mean places for the beginning of the year. Seventeen observations were made of the R.A. of the Moon's bright limb, and two of the horizontal diameter.

With the Equatoreals twenty-one occultations have been observed. The final equations in the Greenwich form have been computed for forty-seven occultations, observed between 1884, October 4, and 1887, February 10.

Comet 1886 I. (Fabry) was observed for place altogether on nineteen nights between 1885, December 7, and 1886, April 1; Comet 1886 II. (Barnard), on fourteen nights between 1885, December 27, and 1886, April 15; Comet 1886 V. (Brooks I.) on four nights between May 6 and May 20. These observations are completely reduced, and all the comparison of stars have been observed on the Meridian two or three times. Comet Barnard-Hartwig, at present visible, has been observed for place on seven nights between December 19 and January 5.

The 18-inch Reflector has been fitted with a new declination-axis, and is now sufficiently rigid; but the driving movement is very irregular.

An instrument by Kahler, of Washington, D.C., for determining absolute personal equations in observing transits, has been brought into use with the Morse chronograph.

### *Mr. Wigglesworth's Observatory, Scarborough.*

The building of the observatory was commenced in the summer of 1884, and by the end of the year the dome was ready for the reception of the instrument. The dome is 30 feet in diameter, hemispherical in shape, and covered with very strong papier-mâché, $\frac{1}{8}$ inch in thickness, which is rivetted with copper rivets to the framework of T-iron. The shutter is of a construction originally introduced by Messrs. T. Cooke & Sons. It has the form of a semicircle striding over the dome. The tail end terminates as a pivot, while the other end, which is the base of the real shutter, rests on a rail. The shutter therefore turns round the pivot in a circle of more than 30 feet radius. It moves with great ease, and practically without noise. On the top of the dome is another rail, to steady the shutter in case of a strong wind. The slit has a width of 5 feet 10 inches at the bottom, and of fully 3 feet at the top. The dome is supported by a brick wall 13 feet in height from the floor to the top of the flat rail on which the wheels of the dome are running. The dome is turned by a cogwheel running in a rack-circle, and is moved with great ease. The rigidity of the dome is very great; it has never been noticed to shake, even when the wind was very strong.

The telescope, which was also constructed by Messrs. T. Cooke

& Sons, was set up in the dome in February 1885. The object-glass, which is a very fine one, has a clear aperture of 15·5 inches, and a focal length of 231·5 inches. The mounting is executed in Cooke's well-known style. Both the polar axis and the declination axis are of steel. There are no friction wheels to the latter, but the instrument turns with great ease in declination. The hour circle reads to 2 seconds of time, and the declination circle to 10 seconds of arc. The latter is read from the eye end of the instrument. The clamps and slow motions in right ascension and declination are worked from the eye end. The driving-clock is of the same construction as that at Dunecht, but without the electric control. There are two finders of 2·5 inches aperture. In front of the object-glass is an iris-diaphragm, by which the aperture may be reduced down to 4 inches. It is worked by a rod from the eye end, and the aperture is read off on a dial. It has been found very convenient on many occasions; the full aperture, however, gives as a rule the best definition.

The mean-time clock is believed to be a unique specimen. It was invented and made at the beginning of this century by George Prior, who was a watchmaker in Leeds, and who received a medal of the Society of Arts for the escapement in this clock. For a long time it was the standard clock of Leeds; after the death of George Prior, however, it came into the possession of Mr. Wigglesworth. The impulse received by the pendulum is independent of the train of the clock; it is given every alternate second by a spring, which is then pushed back to its starting-point by a tooth of the escapement wheel. There is a great difference between the two drops of the escapement wheel; the one is nearly three times as large as the other, and on this difference depends the impulse given by the spring to the pendulum. At the long drop the spring is pushed back; at the short drop it is released, and gives impulse to the pendulum until it is arrested by the next tooth of the escapement wheel. The length of the drop is best seen by the motion of the seconds hand, which shows alternately long and short seconds; the beat, however, is perfectly even—one second is as long as the other. The locking is effected by jewelled detent springs, which are independent of each other. Steel and zinc bars form the compensation of the pendulum, and by the addition of a very small mechanism they have also been made to act as a metallic thermometer. The clock keeps very good time, and has a clear, sharp beat.

There are two spectroscopes by Browning, a reversion spectroscope for observing the Sun, and a McClean star spectroscope.

A micrometer by Merz was kindly lent by Lord Crawford in July 1885. It has only one micrometer screw, but a fine movement can be given to the whole micrometer by two screws in

the adapter, which is a more convenient arrangement than to have two micrometer screws.

Regular observations were commenced in September 1885.

The value of the micrometer screw was determined from numerous transits of *Polaris*.

The new star in *Andromeda* was observed on fourteen nights, and the results have been published in the *Monthly Notices*.

Nova *Cygni* was examined on several occasions.

Gore's new star was examined with the spectroscope and measured from neighbouring stars on two occasions.

The dimensions of *Saturn* were also measured with the micrometer.

Comet 1885 *a* Barnard was observed for place on two nights.

Comets 1885 *d* Fabry, and 1885 *e* Barnard, were each observed on five nights.

In 1886 the observations were of a similar kind.

The dimensions of *Saturn* were measured on one occasion.

The nebula in *Andromeda* was examined on several occasions, but no changes could be detected in it. The same was the case with Nova *Cygni*.

Gore's new star was measured on three nights.

Comet 1885 *e* Barnard was observed once in this year.

Comet 1886 *f* Barnard-Hartwig was observed on twenty-one nights, and some sketches of it were also made.

Comet Finlay was observed twice.

The minor planet *Sappho* has been observed six times at the request of Mr. R. Bryant.

A want of star places has often made a delay in the reductions inevitable.

The adopted co-ordinates of the observatory have been taken from the 6-inch survey map, and are—

Longitude of Observatory $= 1^{m}\ 38^{s}{\cdot}9$ west of Greenwich.
Latitude ,, $= +\ 54^{\circ}\ 16'\ 30''$.

The height above the level of the sea is about 150 feet.

## *Royal Observatory, Cape of Good Hope.*

The present report includes the period January 1 to December 31, 1886.

Observations with the transit-circle have been continued regularly throughout the year, the objects of observation being the Sun, *Mercury* and *Venus*, the stars on the list of the Cape Ten Year Catalogue for 1890, comet comparison stars, stars occulted by the Moon, stars employed in determining latitudes in connection with the Geodetic Survey, and stars employed in

zones for determining the scale-value of the heliometer. The work accomplished has been:—

| | | | |
|---|---|---|---|
| Number of determinations of collimation | . . . | 53 | |
| ,, ,, level | . . . . | 510 | |
| ,, ,, Nadir Point | . . . | 463 | |
| ,, ,, runs | . . . . | 455 | |
| ,, ,, horizontal flexure | . . | 47 | |
| Observations of meridian mark (from April 5) | . . | 439 | |
| | | Direct. | Reflex. |
| Number of observations of stars in R.A. | . | 5333 | 634 |
| ,, ,, ,, N.P.D. | . | 4531 | 634 |
| Observations of both limbs of the Sun in both elements | . . . . . . . . | 191 | |
| Observations of Mercury in both elements | . | 109 | |
| ,, Venus ,, ,, | . | 142 | |

The errors of all the new steel screws of the circle microscopes have been very thoroughly determined; and they prove, though small, to be appreciable.

Since April 5 regular observations have been made on a meridian mark, placed in the focus of a lens of about 200 feet focal length, situate to the south of the transit-circle. This mark is observed at the beginning and end of each series of observations, and it appears that the transit-circle has a very small diurnal motion in azimuth, over which observations of the mark afford an efficient control. During the winter period, April 1 to September 30, observations were regularly made on every available morning before sunrise as well as in the evening; thus a large number of double transits of circumpolars have been secured.

A great deal of time and care have been devoted to the Great Indian Theodolite, the study of its constants, and the development of the best plan of working. The errors of division of the horizontal circle have been thoroughly investigated—a work of great labour, requiring special adaptations in consequence of the peculiar form of the instrument, and of which an account will be communicated to the Society. The best arrangement of the azimuth marks has been a matter of considerable experiment. When the space between the marks and the long focus lenses is left open the images of the marks are generally ill-defined, because of ascending currents of air from the soil which has been heated by a strong sun during the day. The experiment was tried of enclosing the space between one long focus lens and the corresponding mark by means of a wooden tube or tunnel 1 foot square. The effect was to produce a great apparent improvement in the steadiness and sharpness of definition of the mark; but, unfortunately, measurements showed

that this improvement was accompanied with a slow oscillation of the mark, which seemed far more likely to produce systematic error than the rapid irregular vibrations of the marks before the tube was used. It is possible that by protecting the tube from direct rays of the Sun, by means of a long narrow shed, with sides as well as roof, this slow movement of the mark might be reduced or eliminated; but the experiment was not carried out because of its considerable cost and its problematical success. Accordingly, after much experiment, the wooden tube was removed, and the observations were resumed with open-air space between the lenses and the marks. The stability of the relative azimuth of the marks continues to be very satisfactory. The illumination of the theodolite by small incandescent lamps and storage batteries has proved most successful, and the system has been extended to the azimuth marks and the zenith telescope with the most satisfactory results. Indeed, any one who has once employed electric incandescent lamps for illumination of his instruments, especially in a windy neighbourhood, will never willingly return to the flicker, heat, and general inconvenience of oil lamps. A proposal has been made, and partly carried out, for extending electric illumination to all the instruments of the Observatory.

The following observations have been made with the Great Theodolite:—

| | |
|---|---|
| Observations of meridian marks . . . . . | 73 |
| Azimuths at greatest elongation . . . . | 229 |
| „ of N. Stars for latitude by Kapteyn's method . | 32 pairs. |

With the zenith telescope an investigation has been made of the value and temperature-coefficients of the screw by observations in summer and winter, and 104 pairs of stars have been observed for difference of meridian zenith distance.

The general rule has been adhered to of observing all comets visible south of the Equator, or which otherwise cannot be conveniently observed in the Northern Hemisphere. The fulfilment of this programme has led to a considerable amount of work in the past year.

Winnecke's Comet, which was only seen during fourteen days in 1875, and not at all at the opposition of 1881, was swept for and found by Mr. Finlay on August 19, $5\frac{1}{2}°$ from the predicted place of Dr. Lamp's *Ephemeris* (*Astron. Nach.* 2,720, 2,731), corresponding to a time of perihelion passage twelve days earlier than predicted.

On Sunday, September 26, Mr. Finlay discovered another periodic comet, which, if identical with the comet of De Vico, has not been observed since the year of its discovery in 1844.

The following is a list of the observations of comets made during the year:—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fabry | was observed on | 31 | nights | between | May 1 | and | July 30. |
| ☄ Barnard | „ | 18 | „ | „ | May 29 | „ | July 26. |
| ☄ Brooks I. | „ | 13 | „ | „ | July 5 | „ | July 30. |
| ☄ Winnecke | „ | 32 | „ | „ | Aug. 19 | „ | Nov. 29. |
| ☄ Finlay | „ | 34 | „ | „ | Sept. 26 | „ | Dec. 28. |

A paper containing the results of these observations will be communicated to the Society at the March meeting.

Occultations of thirty-two stars and three planets by the Moon have been observed during the year.

The result of observations of stars with the transit-circle for 1882, 83, 84, and till 1885, February 7, are reduced, and will be passed through press by H.M. Astronomer when in England. The Catalogue for 1885, from the meridian observations 1879–85, is in progress.

Aided by the vote of 300*l.* from the Government Grant Fund of the Royal Society, the services of Mr. C. Ray Woods have been continued as photographic assistant.

The extension of the Photographic *Durchmusterung* has been pushed forward as rapidly as possible. Pictures for the whole sky from declination $-57°$ to $-90°$ have now been obtained in duplicate, and considerable progress has been made in further zones towards the Equator. The following amount of work has been secured during the year:—

| | |
|---|---|
| Perfectly successful *Durchmusterung* plates, exposed one hour in clear sky | 263 |
| Plates for special purposes | 37 |
| Plates exposed for more than an hour, such as comets, star clusters, &c. | 11 |
| Failures | 16 |
| | 327* |

The new photographic objective of 9 inches aperture and 9 feet focus, presented by Mr. Nasmyth, has been received from Mr. Grubb, and also a new 6-inch Dallmeyer rapid rectilinear lens (bought by a grant from the Government Grant Fund of the Royal Society). These, together with a guiding telescope of 5 inches aperture and 9½ feet focal length, have been mounted after a design by H.M. Astronomer on a single powerful stand at his private expense, and the work has been continued since September 30 with the new apparatus. This apparatus is fitted with refined means for centring, and with fine scales for focussing, and also with means for giving definite orientation,

* The dismounting of the old apparatus, and the erection of the Nasmyth telescope, &c., in a more convenient observatory, caused some interruption of regular work.

defined by a ground edge on the sensitive plate, which edge rests by spring pressure upon two cylinders that have rigid relation to the declination axis. The dark slides are of metal. The whole apparatus was made by Mr. Grubb, and is found to give very satisfactory results.

Each picture of the *Durchmusterung* photographs taken with the Dallmeyer lens has now a corresponding picture for the central position of its area (perfect over four square degrees), taken simultaneously by means of the Nasmyth lens, and showing stars to a higher order of magnitude. The enumeration of the stars in the corresponding areas of the two pictures will furnish very valuable data for discussing the distribution of stars of different orders of magnitude, after the comparative light-factor for the two lenses has been accurately determined. Some pictures of remarkable star clusters, &c., have been obtained with the Nasmyth lens.

For the reduction of the *Durchmusterung* pictures, H.M. Astronomer has received a noble offer of co-operation from Prof. J. C. Kapteyn, of Grœningen. Appreciating the importance of the work, and the suitability of the means to the end, Prof. Kapteyn proposed to devote his own time and that of three assistants during the next seven years to measurement and reduction of the *Durchmusterung* photographs, and the preparation of a catalogue somewhat resembling that of Argelander. Such an offer from one so capable and so devoted could not but be gratefully and cordially accepted. Accordingly the pictures from S.P.D. 0° to 13° were forwarded to him, together with duplicate plates of an area in the neighbourhood of the Equator for comparison with Argelander. This comparison showed that whilst with a *very few* exceptions (probably red stars) *all* the stars of the *Durchmusterung*, including those of the 9·5 magnitude, are shown on the plate, there are about 30 per cent. more stars on the plates than are contained in Argelander's work. After much discussion by correspondence, a method of observation was arranged by which the Right Ascensions and Declinations of the stars, reduced to the equinox of the Catalogue, are obtained directly from the instrumental measurement; the instrumental results require only small final corrections for index errors, orientation, &c., which can be easily tabulated from comparison of the instrumental and tabular R.A. and Declin. of the known stars. A rough temporary apparatus was arranged by Prof. Kapteyn, which it was resolved to employ for obtaining preliminary plates of the stars within 10° of the South Pole, and with the working catalogue so formed, it will be then easy to observe all these stars in zones with the Cape transit-circle. Thus the first portion of the *Durchmusterung* would be published with places exact to 1″ of arc. With the preliminary apparatus Prof. Kapteyn had already measured in duplicate all the stars within 10° of the South Pole from R.A. $23^h\ 10^m$ to $9^h\ 50^m$. The accuracy obtained with the

rough apparatus has exceeded expectations, as will be shown by the following comparison of the instrumental R.A. and Declin. with corresponding tabular places of the Cape 1880 Catalogue:—

| By | | Deduced Decln. of zero of scale. | Index error in R.A. |
|---|---|---|---|
| | | ° ′ | ″ |
| Zone IX. | Stone 2948 | 80 29·5 | + 16 |
| | 3290 | 29·5 | + 15 |
| | 3380 | 29·5 | + 10 |
| | 3457 | 29 6 | + 18 |
| | 3680 | 29·5 | + 18 |
| | 4084 | 29·7 | + 18 |
| | 4486 | 29·5 | + 20 |

The Declinations are read off by estimation to 0′·1, from a glass scale, graduated to 1′ of arc, placed in focus of the small telescope by which the photograph is viewed; and the R.A. is read off by estimation to $2^s$ of time, by a small circle graduated to $20^s$ attached to and rotating with the axis, which serves as the polar axis of the arrangement. There seems to be little doubt that, with a more refined measuring apparatus the places of stars can be determined from the photographs to a single second of arc, without much additional trouble on the part of the observer. An apparatus amply providing for this accuracy has been devised by H.M. Astronomer, and he hopes to be able to have it executed during his approaching visit to Europe.

A very laborious attempt has been made since July 20, 1885, to photograph the Corona by Dr. Huggins's method. From time to time some of the pictures obtained showed persistent similarity, under conditions which appeared to preclude the possibility of instrumental error, but no gradual change could be traced in these appearances, such as one might expect in the representation of successive features of the true Corona.

With every confidence in the method, and with laborious care, some hundreds of these pictures have been taken and examined in different ways and in different lights, and the appearances have also been discussed in relation to the elongations of *Mercury* and *Venus*, as suggested by Dr. Huggins. The most hopeful series have been independently drawn by Mr. Wesley, with results as to the general features of the pictures of the same day coinciding with those remarked at the Cape, but the results, while sometimes leading to hope of success, have never brought the conviction that the true Corona had been really photographed. The crucial test as to whether the dark body of the Moon could be photographed against the background of the Corona was tried under favourable atmospheric

conditions on the occasion of the partial eclipse of August 29. No trace whatever of the dark body of the Moon outside the Sun's limb could be discovered on the pictures, and it appears that further experiments in this direction, to be successful, must be made at a higher altitude, or at a time when the Sun's Corona is brighter than the recent eclipse observations show it to be at present.

The new observatory for the heliometer is completed. Messrs. Repsold report that the new heliometer will be finished in the end of February, and H.M. Astronomer has received instructions from the Admiralty to visit Europe for the purpose of inspecting it before it is sent to the Cape.

The Geodetic Survey continues to make considerable progress, notwithstanding somewhat disheartening conditions—viz. reduction of the vote by one-third of its amount, on account of the depressed financial condition of the Colony. In consequence of this reduction the services of Lieut. Laffan, R.E., have been transferred to the Survey of British Bechuanaland, the staff otherwise reduced, and the equipment and transport reorganised. Captain Morris, R.E., has carried on the field work in these new and more trying conditions with the same energy and ability as formerly. The triangulation has been carried from Natal through Griqualand East to King William's Town in the Cape Colony, and the stations have been selected and beaconed from King William's Town to Port Elizabeth.

H.M. Astronomer has taken part in measurement of a base line at Port Elizabeth, of which an account will be communicated to the Society. The extension of this base to the first great side is now in progress. The subsequent measure of the angles of the triangles already selected and beaconed between Port Elizabeth and King William's Town will be completed in June, when Baily's existing triangles between Sir T. Maclear's southern stations and Port Elizabeth will complete a chain of triangles about 1,300 miles in length, checked by three base lines and with numerous astronomical stations, which should afford some valuable geodetic data.

Lieut. Laffan, R.E., has compared his personal equation with Mr. Pett at the Observatory on four nights, not by the usual methods, but by actual determination of the longitude of a hut on the Observatory grounds by telegraphic exchange of signals, as in the ordinary process of a longitude operation; the results, therefore, include the relative personal equation of the observers in giving and receiving signals as well as in determination of time.

The longitude of the following points on the Geodetic Survey have been determined by telegraphic exchange of signals with Captain Morris:—

*Umtata*, by exchange on 6 nights.

*Berlin*, „ „ 4 „

and the longitude of Dryhartz, in British Bechuanaland, by exchange of signals with Lieut. Laffan, R.E., on five nights.

The heavy pressure of a great variety of work requiring the close personal attention of H.M. Astronomer has rendered it impossible to complete the reduction of the observations of *Victoria* and *Sappho* in 1882, but it is expected that the work will be pushed to completion before the end of the year.

The Meteorological Observations made in the year 1885 at the Observatory, together with those taken in different parts of the Colony, have been printed in the Reports of the Cape Meteorological Commission.

### *Hong Kong Observatory.*

The second annual volume was published early in the summer, and the third volume will probably be ready for distribution within a few months. The meteorological observations and researches have been extended, and kept up to date since the appointment of an additional clerk. Absolute magnetic observations were made monthly, and Sir W. Thomson's automatic tide-gauge was erected and worked since the end of October.

The electric time-ball was dropped as usual at 1 P.M., and the sidereal standard clock was kept going without being touched throughout the year. As soon as two years' ten-day rates are available, it is intended to re-examine the coefficients.

Micrometric measures of *Jupiter* and *Saturn* occasionally made since 1879 have been reduced, and will be published in the astronomical Report.

## Notes on some Points connected with the Progress of Astronomy during the past Year.

### *Discovery of Minor Planets.*

The following eleven minor planets were discovered in the year 1886:—

| No. | Name of Planet. | Date of Discovery, 1886. | Discoverer. | Place of Discovery. |
|---|---|---|---|---|
| 254 | Augusta | Mar. 31 | Palisa | Vienna |
| 255 | Opparia | 31 | " | " |
| 256 | Walpurga | Apr. 3 | " | " |
| 257 | Silesia | 5 | " | " |
| 258 | Tyche | May 7 | Luther | Dusseldorf |
| 259 | Aletheia | June 28 | Peters | Clinton |
| 260 | Huberta | Oct. 3 | Palisa | Vienna |
| 261 | Prymno | 31 | Peters | Clinton |
| 262 | | Nov. 3 | Palisa | Vienna |
| 263 | | 3 | " | " |
| 264 | Libussa | Dec. 22 | Peters | Clinton |

Minor planet No. 253, discovered by Herr Palisa on November 12, 1885, has been named *Mathilde*.

### *The Comets of 1886.*

Including the periodic comet of Winnecke, six comets have been discovered during the year. It will be more convenient to describe these in the order of their discovery, than according to their several dates of perihelion passage or catalogue order.

The first (known as 1886, Comet V.) was discovered by Mr. Brooks, of Phelps, New York, on April 27, in the constellation *Cassiopeia*, and moving south and east. At the time of discovery it was round, tolerably bright, and about one minute in diameter. The comet was approaching both the Sun and the

Earth, and the brilliancy consequently increasing. The maximum brilliancy was attained about June 9, near the date of perihelion passage, when it had twenty times the intensity that it possessed when first seen, but was too near the Sun to permit of observation. After perihelion, the comet was not well situated for observation, and does not seem to have been seen. The observations are well represented by a parabola.

Four days later, on May 1, Mr. Brooks discovered another comet in the constellation *Pegasus* (designated 1886, Comet III.). This comet was fairly bright, and had on May 3 a short tail, eight minutes in length. Owing to the morning twilight the comet soon became a difficult object to observe, and was apparently lost sight of in the third week of May, but the change of form in the comet was interesting. On May 20, Col. Tupman could see no trace of a head, and the two ends of the tail were so similar, it was impossible to say by mere inspection, which was the head. On May 22 Dr. Tempel gave a very similar description, but suspected two very slight condensations in a spindle-shaped nebulous mass, about twelve minutes long.

As in the previous case the orbit is apparently parabolic, but some interest attaches to the elements, since at the ascending node which the comet passed on July 9, its distance from the Earth was only 0·075, and therefore might have originated a meteor-radiant, visible in the southern hemisphere, the coordinates being approximately $\alpha = 19°$ and $\delta = -42°$.

On May 22, Mr. Brooks discovered a third comet (1886, IV.), which does not appear to have been observed very frequently, the more to be regretted, as the comet's orbit will probably prove to be elliptic. Dr. Oppenheim, failing to represent the path with sufficient accuracy by means of a parabola, has computed an elliptic orbit of nine years' period, which fairly well represents the few observations at his command.

Comet 1886 VI. is the periodic comet of Winnecke, detected by Mr. Finlay at the Royal Observatory, Cape of Good Hope, on Aug. 19, the possibility of the comet being found in the northern hemisphere during the summer months not having been realised. The last return of this comet was in 1880, when, owing to its proximity to the Sun, it passed unobserved. In the interval, 1880–1886, the comet underwent very considerable perturbations from *Jupiter*, to which planet, in heliocentric longitude 110°, it can approach within 0·06. No accurate calculations of the perturbations were undertaken, but Dr. Palisa gave sweeping Ephemerides from elements approximately corrected. These elements show that the chief effect of the perturbation has been still further to diminish the mean motion, which had been steadily decreasing since the re-discovery in 1858. The passage through the perihelion was, however, twelve days earlier than was predicted by Dr. Palisa. It cannot be doubted but that rigorous calculations will be made in order to connect the observations of this year with those of the earlier apparitions,

since, according to the late Dr. Oppolzer, the theory of the comet cannot be satisfactorily reconciled with observation on the purely gravitational theory, but that the mean motion and eccentricity require the correction of small terms, depending on a supposed resisting medium.

On September 26, Mr. Finlay discovered another comet, in the constellation *Scorpio*, having small south-easterly motion. The comet was round, one minute in diameter, and without tail. As soon as the elements were computed, it was seen that they strongly resembled those of De Vico's comet of short period, which had not been seen since 1844. There are, however, some difficulties in accepting the suggestion that the two comets are identical, and the doubt cannot be cleared up till the mean motion of the comet is sufficiently well determined to permit the rigorous calculation of the perturbations of the comet by *Jupiter* (and possibly *Mars*) in the interval.

The period assigned by Dr. Brunnow was 5·466 years, and if we assume that either eight or seven returns of the comet had occurred between 1844 and the present time, we must admit either the action of very considerable perturbation, which is not likely, or that Brunnow's period was more in error than seemed possible, though it is admitted that the change of form in the comet during visibility in 1844 may explain the existence of a larger error than has hitherto been suspected. The more accurate elements that have been computed from a more extended series of observations, and in which no assumption of the axis major has been made, agree in giving a period considerably longer than that found by Dr. Brunnow, so that it is not impossible that the two comets may not be identical, but two moving in a similar orbit, an example of which was seen in the case of Comets 1843 I., 1880 I., and 1882 II.

The sixth comet of the year was discovered on October 4 by Mr. Barnard, and independently by Dr. Hartwig on the following day. The comet at discovery was round and tolerably bright, and was increasing in brilliancy. By October 29 a short broad tail was visible, and early in December this tail had increased to several degrees in length, and a shorter tail of 15′ in length, and distant 40° of position angle had been developed. These details have been satisfactorily photographed by Von Gothard, of the Physical Observatory of Herény. It was seen with the naked eye in Turin on November 21, but was too near the morning twilight to become a conspicuous object. The orbit is apparently parabolic.

In addition to these comets, it is well to remark that Olbers' Comet, to which reference was made in the last Annual Report, has not yet been detected, and that as the most probable time of perihelion passage has now been reached the search should be severely maintained. A comet, which was discovered by Tempel on November 27, 1869, and re-discovered by Swift on October 11, 1880, has probably passed this year through perihelion unde-

tected. The orbit has been rigorously computed by M. Bossert of the Paris Observatory, who gave an ephemeris to assist the search. It is a peculiarity of the comet that it is well situated for observation at alternate returns, and this approach was unfortunate, the theoretical brilliancy never attaining one-tenth of that possessed by the comet at the last recorded observation.

W. E. P.

## *The Total Solar Eclipse of* 1886, *August* 28–29.

The expedition sent out to Grenada, West Indies, to observe this eclipse, consisted of the following persons: Captain Darwin, Mr. Lockyer, Mr. Maunder, Father Perry, Dr. Schuster, Professor Thorpe, and Mr. Turner. Professor Tacchini also accompanied the expedition on behalf of the Italian Government. The observers divided into several parties on reaching Grenada, as a precaution against purely local masses of cloud, or bad weather; it being also arranged that observations should be made as far as possible in duplicate. Although the weather at the time of the eclipse was not all that could be desired, successful observations were secured at three stations; at the fourth the Sun was obscured by heavy clouds.

The following is a brief account of the results obtained, taking the stations in order from the south:—

Station I.—*Prickly Point*, lat. 12° 0′ N., long. 61° 46′ W. Captain Darwin with the coronograph exposed six plates during totality, one for five seconds, one for ten seconds, and four instantaneous. During the partial phases he obtained more than twenty satisfactory photographs, and on the day before the eclipse, fifteen. These were all taken with the object of testing Dr. Huggins's method for photographing the Corona without an eclipse, and the result, as far as is yet known, is unfavourable to that method, under such conditions of hazy sky and low sun as were obtained.

Captain Darwin also took one photograph with the prismatic camera.

Dr. Schuster obtained four photographs of the Corona with a 5-foot camera, and two of the coronal spectrum, with slits radial and tangential respectively.

Station II.—*Hog Island*, lat. 12° 0′ N., long. 61° 44′ W. Professor Thorpe, assisted by Mr. Lawrance, obtained a satisfactory series of photometric measures of the intensity of the Corona. He made in all fifteen separate and independent comparisons of the coronal and diffused light beyond the visible edge with a Swan electric lamp of known photometric value, by a method arranged by Captain Abney. During the latter part of totality

the coronal light was dimmed by haze, but he sees no reason for thinking the measures made in the first hundred seconds other than perfectly trustworthy. Relying on these seven only, the final photometric values obtained are not very different from those found by Professor Harkness in the 1878 eclipse.

Station III.—*Boulogne, near Grenville*, lat. 12° 9′ N., long. 61° 38′ W. Professor Tacchini made a careful comparison of the prominences detected by the spectroscope before and after totality with those seen during totality, and found important differences between them, viz.: all prominences showed themselves larger and taller during an eclipse, the upper portions being white when the prominence exceeds 1′ of arc in height, while some very fine prominences seen during totality were not discernible in full sunshine at all; these latter were almost entirely white, and their luminous intensity was small, so that they were not visible to the naked eye unless they extended beyond the brightest part of the Corona. He also observed the spectrum of the "flash" noticed by Professor Young in 1870, and traced it to a much greater height than before.

Mr. Turner obtained a qualified confirmation of Mr. Lockyer's Egyptian observations with regard to the order of appearance of the bright lines near F in the spectrum of the inner Corona. During totality he looked for currents in the Corona, but obtained no satisfactory results.

Station IV.—*Green Island*, lat. 12° 14′ N., long. 61° 35′ W. Cloudy during totality. Mr. Lockyer considers, however, that important information was obtained by preliminary drills as to the number of photographs which could be taken during totality by careful management.

Station V.—*Hermitage, Carriacou*, lat. 12° 27′ N., long. 61° 29′ W. Father Perry made observations of the order of appearance of lines in the coronal spectrum near E., and observed 1474 K and other short bright lines two minutes before totality. During totality he looked for the carbon flutings seen by Professor Tacchini, but with a negative result.

Mr. Maunder obtained seven photographs of the Corona with a 5-foot camera, exposures varying from 0ˢ·2 to 40ˢ, and two photographs of the coronal spectrum with slits radial and tangential.

Almost at the last moment another observer arrived on the scene. Mr. W. H. Pickering, from Boston, Mass., took up his position in Fort George, lat. 12° 3′ N., long. 61° 45′ W., armed with a photoheliograph of 38 feet focal length. He exposed a number of plates during totality, and also organised a series of observations of the shadow bands.

The observers owe a very large debt of gratitude to the Governor of Grenada, who helped them in every way, and they received invaluable assistance from the leading officials, and from the officers and crews of H.M.S. *Fantôme*, H.M.S. *Bullfrog*, and

H.M.S. *Sparrowhawk*, both in transport and preparations for observing, and in the actual observations. A number of discs had been taken out with the view of repeating Professor Newcomb's observation of 1878 on the coronal extension, and fairly accordant results were obtained by the following observers at the different stations:—

I. Captain Maling, Colonial Secretary.
II. Captain Archer, of H.M.S. *Fantôme.*
III. Lieut. Smith, of H.M.S. *Sparrowhawk.*
IV. Captain Hughes, Protector of Immigrants, and Mr. Belton.
V. Captain Masterman and Mr. Osburn, of H.M.S. *Bullfrog.*

At Station II. also Lieuts. Douglas and Bairnsfather, of H.M.S. *Fantôme*, made a series of photometric measures with an integrating apparatus, which agree with Professor Thorpe's general results. The Governor of Grenada, the Chief of Police, the Clerk of the Council, Dr. Boyd, Mr. Elliott (Government Botanist), and Captain Oldham, of H.M.S. *Sparrowhawk*, were all busily engaged at Station IV., and were prepared to assist in the photographic operations.

On the whole, the expedition may be considered a very successful one, and the passing clouds which obscured part of the phenomenon at the more fortunate stations served perhaps to remind the observers how nearly they had escaped complete failure.

H. H. T.

### *Professor Hall's Researches on the Orbits of the Six Inner Satellites of Saturn.*

In Appendix I. of the Washington Observations for 1883 Prof. Asaph Hall communicates the positions of the six inner satellites of *Saturn*, observed with the 26-inch refractor, and the results of the computations to which they have been subjected.

The observations of Titan, which extend over nearly ten years, from August 1874 to February 1884, consist partly of measurements of differences of Right Ascension and Declination between the satellite and the centre of the planet, and partly of measurements of position-angle and distance. The observed positions are compared with the corresponding places computed with the values of Bessel's tables in vol. 9 of the *Astron. Nachrichten.* Bessel's determination of the elements of the orbit there given is founded upon the first series of his own heliometrical measurements of Titan, taken in 1830, the mean motion of the satellite in its orbit and the motion of the line of apses being deduced from a careful discussion of the scanty observations of conjunctions of the satellite with the centre of the planet made by Halley, Cassini, Herschel, and Köhler. The

Washington computations show that only small corrections of the tabular values are demanded by the Washington observations. Indeed, the correction of the motion of the apses is left doubtful; for, while the earlier series of observations made from 1874 to 1882 indicate a slight augmentation, only the last series made 1883–84 show a diminution, and it will have to be decided by further evidence what is the true motion.

From his computations of the micrometrical measurements of Rhea, Dione, and Tethys, which were made in the years 1874 and 1875, Prof. Hall draws the conclusion that the eccentricities of the orbits are left practically undetermined, and also that the planes of the orbits probably coincide very nearly with the plane of the ring. For the determination of the mean motions of the satellites he assumes that the mean longitudes for the epoch 1858, which Jacob has deduced from his Madras observations, are free from error, and the values of the daily motion resulting from the positions of 1858 and 1875 are then partly corrected with the help of the conjunctions observed at Washington in the years 1882 to 1886. In the case of Mimas, the mean motion is simply deduced from seven conjunctions, observed within three years and a quarter. But, as the adopted motion leaves an error of about half an hour in Herschel's trustworthy observation of October 18, 1789, the value cannot be accepted as sufficiently correct. A. M.

*The Argentine General Catalogue of Stars.*

It was only in the middle of the year 1872 that observations with the Cordoba Meridian Circle were commenced, and by the end of 1880 no less than 145,000 observations had been made, suitable for the General Catalogue, and more than 105,000 zone observations. It is probable that the whole of the meridian work of all the other observatories in the world put together during the same interval would fall short of these numbers. Only seven years ago the state of our knowledge of the southern heavens was deplorable. The publication, in 1881, of Mr. Stone's great work at the Cape and of the present truly wonderful work of Dr. Gould and his able assistants, during the last few months, has suddenly turned the scale so completely that the southern heavens are now more thoroughly surveyed than the northern, and must remain so until all the zones of the Astronomische Gesellschaft have been united into a complete catalogue. The rapidity with which the reductions have been effected and published is no less amazing than the observations themselves. Nothing like it has been known in the history of astronomy.

The instrument is described in the introduction to the observations in 1872. Several volumes of the observations and the Zone Catalogue have already been published. The present

volume forms No. XIV. of the series. It contains the places of 32,448 stars south of the parallel of N.P.D. 113° in the body of the Catalogue, and of 1126 stars in remarkable clusters arranged as separate small catalogues. The epoch is 1875·0. The arrangement of the Catalogue exhibits separately each year's results for each star. The annual precessions and secular variations, the epoch of observation, the number of observations and references to other catalogues are given. Most of the stars have been observed at least three times. The adopted mean places of the time and circumpolar stars, used for the determination of the instrumental corrections in each year, are given in the corresponding volumes of observations.

The Right Ascensions of the Catalogue depend exclusively upon 75 time stars of the American *Nautical Almanac*. The declinations are independent.

The stereotype plates of the Catalogue have been presented to the Royal Astronomical Society by Dr. Gould, with the consent of the Government of the Argentine Republic.

### *The Harvard Catalogue of* 1213 *Stars for* 1875·0.

This work, which represents a large part of the labours of Prof. W. A. Rogers for the last fifteen or sixteen years, forms Part I. of vol. xv. of "Annals of Harvard College Observatory." The observations on which it depends were made with the large Meridian Circle, described in vol. viii., between 1870 November and 1879 January. The stars are of two classes; 492 being fundamental stars from Dr. Auwers' Catalogue in "Publication der Astronomischen Gesellschaft," XIV., the remainder, termed secondary stars, being miscellaneous stars observed for various purposes. The observations were concurrent with those of the zone +50° to + 55°, A.G.

The observations of the fundamental stars have been printed in vol. xvi. with an elaborate and masterly Introduction by Prof. Rogers, giving the method of reduction in great detail. The Introduction to the present Catalogue contains the mean places of these fundamental stars separately for each year, and the star ledgers of such of the other stars as are not given in vol. x. or xii.

Instead of the usual spider-lines, a reticule ruled upon glass was employed. The Declinations were measured by recording on the chronograph transits over very oblique lines. For a number of years only two microscopes were used for reading the circle; but Prof. Rogers has elaborately investigated the reduction of the mean of two to the mean of four from the observations of subsequent years.

The Right Ascensions of Publication XIV. were used in determining clock error; hence, for the fundamental stars the

Right Ascensions of the Catalogue are almost exactly reproductions of Auwers'. The same applies to the Declinations. The errors of the circle and accumulated errors of the microscopes were determined by and expressed in terms of Auwers' system of Declinations. The discussion of the observations of the fundamental stars (which are very numerous and of a high degree of accuracy) demonstrates the homogeneity of Auwers' systems. The places of the remaining 720 stars have a corresponding degree of accuracy. For Bradley's stars, Dr. Auwers' original proper motions are given in the Catalogue, and were used for reduction to mean epoch.

### *The Pulkowa Catalogue of* 3542 *Stars for* 1855·0.

This Catalogue, which forms a portion of vol. viii. of the "Pulkowa Observations," has been formed from the observations published in vols. vi. and vii. It contains all Bradley's stars from the Pole to 105° N.P.D., except the Pulkowa fundamental stars, all other stars down to the 6th magnitude inclusive in Argelander's *Uranometria Nova* in the same portion of the heavens, and some other stars which have been added to the observing list from time to time for special purposes. The observations were made with the Repsold Meridian Circle, described in the introductory volume, between the years 1840 and 1869, by MM. Sabler, Döllen, Lindhagen, Winnecke, and Gromadski. The reductions were conducted throughout by M. von Asten.

Each star was observed four times; once in each of the four positions of the instrument obtained by reversing the axis and interchanging the object-glass and eyepiece. The Right Ascensions depend upon those of the Pulkowa Fundamental Catalogue, the Sun not having been observed with this instrument. The Declinations are independent, having been determined from observations of the horizontal collimators combined with the known colatitude. The large number of stars and the completeness with which the plan of observation was carried out make this one of the most valuable catalogues in existence. The delay in the publication has enabled Dr. Auwers' new proper motions to be inserted in the work, and to be used in the reduction to mean epoch.

### *Professor Schönfeld's Extension of the "Durchmusterung."*

An important work has been issued within the last few months from the Royal Observatory of Bonn. Argelander's *Durchmusterung*, or survey of the northern heavens from the Pole to 2° of South Declination, has been carried down by

his successor, Professor Schönfeld (who in conjunction with Professor Krueger was associated with the late Professor Argelander in the former part of the work), to 23° South Declination, and the results are now in the hands of astronomers.

Professor Schönfeld commenced observing on January 6, 1876, and at first proposed to carry his survey down to 24° or 25° South Declination, so as to overlap by a degree or so the northern limit of the Cordoba zones. It was found, however, that −23° was the extreme limit for satisfactory observation. In view of the lower altitude of the stars to be observed, it was decided to substitute for the small comet-seeker of 34 lines aperture, employed in the earlier work, a telescope by Schröder of 6 inches aperture and 6 feet focal length—a change which was further recommended by the fact that for several years Professor Schönfeld had been engaged in magnitude comparisons with a telescope of the same aperture at the Mannheim Observatory. With this instrument, fitted with an eyepiece of 26 mag. power, having a field of 1° 44′, the survey was worked in zones; and the stars thus observed number 133,659 between −2° and −23°, with an additional 1173 stars falling beyond these limits. At the same time, with a view to the more satisfactory designation of the fainter stars, the magnitude limit was extended to 10·0. The resulting catalogue is arranged in zones of 1° of Declination on the same plan, and calculated for the same epoch (1855·0) as the sections of the earlier work, and forms Vol. VIII. of the "Astronomische Beobachtungen auf der Sternwarte zu Bonn."

The catalogue is accompanied by an Atlas, in which the charts are arranged in sheets of one hour of Right Ascension each, with an overlap of four minutes on either side, and extend in Declination from −1° to −23°. The Atlas will be completed in four parts, of which two only have as yet appeared. These contain Hours 0 to xi. (with the exception of Hour vii.), and Hour xxiii.

This valuable work, completing the survey of the heavens on a uniform plan within the limits effectively practicable at an Observatory in central Europe, is appropriately inscribed by Professor Schönfeld to Argelander's memory.

## *The Second Armagh Catalogue of Stars.*

This Catalogue embodies the whole of the meridian work done at the Armagh Observatory since the publication of the first Armagh Catalogue. It contains the places of 3300 of Lalande's stars, from observations between 1859 and 1883 inclusive, reduced to the epoch 1875·0.

The Right Ascensions depend on the standard stars of the *Nautical Almanacs* of the period, four or five of which were

observed on each night. These stars were not observed in Polar Distance. The Declinations of the Catalogue depend upon the Nadir observation which was made every night, the assumed colatitude, and the division errors determined by Dr. Robinson many years ago. The refractions employed were Dr. Robinson's. The precessions are given to three places and two places of decimals in R.A. and N.P.D. respectively, but not the secular variations. The references to other catalogues are copious, and are apparently complete. The observations upon which Dr Robinson's Catalogue of 1000 Lalande's stars depend are included in the present volume.

It was only in February 1882 that Dr. Dreyer was appointed to the directorship of the Observatory, at which time most of the work was unreduced.

### *Dr. Kam's Catalogue of* 5455 *Small Stars.*

Scattered through the volumes of the *Astronomische Nachrichten* are a great number of determinations of the places of small stars, generally comparison stars, not to be found elsewhere. Prof. Schjellerup formed a most useful index to all these stars in the first sixty-six volumes, by reducing all their places approximately to 1855·0, and giving a reference to the volume and page where the accurate place could be found ("Publication der Astron. Gesell." VIII.). That work still remains useful for all stars determined by equatorial comparison with others. Dr. M. Hoek, late Director of the Utrecht Observatory, commenced the task of forming a proper catalogue of all such stars as had been observed with meridian instruments, and his successor, Dr. Kam, has completed it. The body of the work is a catalogue of 4890 meridian observations of 4350 stars, reduced to the epoch 1855·0 by the application of precession. The precessions, secular variations, and third terms are given for the same epoch, a reference to the volume and page of the *Ast. Nach.*, and the name of the observer and observatory. This is accompanied by copious notes and a comparison of every star with its place in the Bonn *Durchmusterung*—the whole involving an immense amount of labour which will be duly appreciated by all who are engaged in equatorial comparison work, and will ultimately assist in determining the proper motion of these small stars.

### *The Great Comet,* 1882. *II.*

Dr. Gill has recently published a complete account of the observations of this comet, which were made at the Royal Observatory, Cape of Good Hope.

Utilising all the means at his disposal, Dr. Gill succeeded in securing a fairly continuous series of positions of the comet from 1882, September 7, to 1883, May 12, to accomplish which, observations were made with the Indian Theodolite, the Transit Circle, the Heliometer, and the 6-inch and 7-inch Equatorials.

In Table I. is given the daylight observations made with the Indian theodolite on September 16, 17, and 18, before and after the comet passed on to the Sun's disc; and the resulting R.A. and declination are computed for the times of observation.

Table II. gives the meridian observations with the Transit Circle. These consist of three observations by Dr. Gill in September 17, 18, and 22, and a series between January 9 and 30, made by Mr. Maclear, who endeavoured to observe the brightest part of the nucleus.

Table III. gives the apparent places of the comet in R.A. and N.P.D. from a long series of observations, with comparison stars made with the Equatorials from 1882, September 7, to 1883, May 12. In the majority of these observations, the centre of the nucleus, or patch of light, was supposed to be observed, but towards the end of the series it was found that one of the observers always observed a more condensed part which slightly followed this centre.

The results of Dr. Elkin's observations with the Heliometer are given in Table IV. In these observations, as in those made with the Equatorials, the same portion of the nucleus was not always observed. The complex character of the nucleus of this comet, and the uncertainty that must exist as to which portion of it the observations refer, will present serious difficulties to the computer.

The memoir is illustrated by several interesting sketches of the head and nucleus of the comet, and by copies of the unique series of photographs so happily secured by Dr. Gill.

### *Professor Hall's Determinations of Stellar Parallax.*

Professor Asaph Hall has published in an Appendix to the Washington Observations for 1883, a further series of observations for stellar parallax.

The method adopted was the same as that employed for the earlier observations, viz. to observe the differences of Declination of the principal stars with respect to small stars near them which are supposed to have no physical connection with the large stars. The method of measuring differences of Declination was chosen because the measurement of distances with the filar micrometer of the Naval Observatory has been found more accurate than that of angles of position; and also because observations had shown that there was no sensible term depending on the temperature in the value of a revolution of the micrometer screw.

Professor Hall's results for the four stars observed give the following values of the parallax :—

| | |
|---|---|
| 40 ($o^2$) Eridani | $\pi = +0''.223 \pm 0''.0202$ |
| 6 B Cygni | $\pi = -0.021 \pm 0.0077$ |
| $\alpha$ Lyræ | $\pi = +0.134 \pm 0.0055$ |
| 61 Cygni | $\pi = +0.270 \pm 0.0101$ |

The parallax of 40 ($o^2$) *Eridani* was obtained by measures of the difference of Right Ascension of a star of the eleventh magnitude $32^s$ following and $48''$ south of the principal star. The distance was so great that, with the power of 383 employed, it was necessary to move the eyepiece in order to bring the stars successively into the field, which introduced an element of considerable difficulty. Dr. Gill's value of the parallax of this star is $0''.166 \pm 0''.018$.

The negative value of the parallax obtained for 6 B *Cygni* is suggested by Professor Hall as indicating a parallax of the star of comparison or some systematic error in the observations of the summer and winter months. The result is strikingly different from Sir R. S. Ball's provisional determination—

$$\pi = 0''.482 \pm 0''.054$$

An error having been detected in the reduction of the observations for determining the parallax of $\alpha$ *Lyræ* and 61 *Cygni*, made in 1880 and 1881 (noticed in the Report for 1882), the result now given for $\alpha$ *Lyræ* is from a re-reduction of the original observations. In the case of 61 *Cygni* two additional series of observations, near the times of the maximum positive and negative coefficients of parallax, were made in 1885 and 1886 and combined with the earlier series re-reduced. Professor Hall's concluded value of the parallax is much smaller than what has been determined by other observers. The author calls attention to the discrepancy, but considers that the results appear to be the best that can be derived from the observations.

## *Stellar Photography.*

The most notable records in relation to stellar photography during the past year are embodied in—

I.—A remarkable article entitled "An investigation in Stellar Photography," forming part of vol. xi. of the *Memoirs of the American Academy*, by Professor Pickering.

II.—A Monograph on Astronomical Photography, by Admiral Mouchez, in the *Annuaire du Bureau des Longitudes*, Paris, 1887.

III.—The article on Stellar Photography contained in the February number of the *Nineteenth Century*, by Mr. Common.

IV.—The Successful Application of Photography to the Determination of Stellar Parallax, by Professor Pritchard, in the January number of the *Monthly Notices* of the Royal Astronomical Society.

V.—A paper in the *Astronomische Nachrichten*, No. 2737, on the photographic work executed in the Imperial Observatory of Potsdam.

Of some of these records it is proposed to give a very rapid outline, referring the Fellows of the Society to the original documents for the various details connected with each. It may be remarked, *in limine*, that in the publications enumerated, there is prefigured nothing short of an entire revolution in the application of instrumental methods to astronomical research. The superb instruments now existing, monuments as they are and ever must be of the genius of a long line of highly gifted men, will not indeed be wholly superseded, but will be mainly valuable as instruments of verification of labours and results obtained, not in painful driblets, but in groups and masses by shorter processes. Astronomers' attention will, in the near future, not be confined to the direct scrutiny of the heavens alone, but to the study of the faithful pictures thereof, taken at will in rapidly occurring successive periods. The consideration of these pictorial views will take the place of laborious catalogues. Potentially they will be such in themselves.

I. *The Harvard Memoir.*—In this memoir Professor Pickering describes a modification of existing forms of camera, consisting mainly of an adjusted compound photographic lens of about eight inches diameter and forty-five inches focal length and controlled by a standard clock, by means of which he can, among other adaptations to be presently described, take pictures of the heavens with considerable facility and sufficiently accurate for maps. With one hour's exposure, stars of a brightness such as those in Peters' and Chacornac's charts can be photographed, and when conveniently enlarged, copies can be printed in permanent ink by some of the many processes known at present. Such maps will be sufficient as charts, but unavailable for the determination of small changes in position. Perhaps these pictorial charts might be supplemented by smaller and more accurate pictures of selected portions of the heavens for purposes of great precision. He entertains the thought that in two observatories, respectively north and south of the Equator, the whole heavens might be charted (to mag. 13?) in less than twelve months. Whether a much wider division of labour and a somewhat extended scale in the order of faintness might not be more desirable will probably be best discussed in the proposed convention at Paris in April next.

Of greater originality, and possibly of even greater value, is

the proposition of Professor Pickering to determine the relative brightness of stars, by availing himself of the traces made by stars on the photographic plate while passing, either by unaltered diurnal motion, or instrumentally retarded, across the field of view. In his hands the method assumes a scientific value entirely different from the haphazard estimates of magnitude hitherto put into practice. For the brighter stars (that is, brighter than the eighth magnitude), even when near the Equator, a trace is formed when the camera is stationary; for others less bright the duration of the transit can be regulated as need requires. It is obvious that as the stars approach the Pole, the traces made during a given exposure of the plate become shorter and therefore necessarily are actinised to a greater extent, depending on their length. When the camera has been pointed to the Pole, traces of stars, even of the thirteenth and fourteenth magnitudes, have been photographed with a stationary telescope. A scientific method of estimating relative brightness thus becomes available, it being always premised that a scale of magnitudes, depending on the breadth and length of the traces, has been carefully prepared beforehand. The details of the process must be gathered from the original memoir, and will amply repay the attention of the reader. It should be added that Professor Pickering has successfully applied his method numerically to stars in the *Pleiades*, and to others near the Pole.

The most remarkable and valuable part of Professor Pickering's memoir is that in which he applies the method of trails or traces to the photography of stellar spectra. Hitherto the method of using a narrow slit, supplemented or not by a cylindrical lens, and requiring extreme accuracy in the driving clock, and even then a continued personal vigilance for the manual correction of its irregularities, has proved a most serious drawback in the register of stellar spectra by the aid of photography. By the method of traces the slit, the cylindrical lens, and the painful watching are dispensed with. A prism (of 15°, as used by Professor Pickering) is placed in front of the objective, with its refracting edges horizontal when the star is on the meridian. In this way the star impresses its own spectrum, with the lines thereto peculiar, on the sensitised plate. In the case of the brighter stars the telescope itself remains stationary during the time of exposure; in the case of fainter stars, which require a longer time to impress their traces on the plate, the instrument is driven at any convenient rate, so as to produce in a given time a line of the necessary length. In point of fact, the light of the star itself, by diurnal motion, becomes virtually a line of light, or illuminated slit, which is dispersed into its spectrum by the refracting prism. Professor Pickering, in his memoir, gives an enlarged photographic picture, containing examples of this method applied to the *Pleiades* and some of the brighter stars. The process gives the promise of great facility, and probably great accuracy, amply sufficient for the determi-

nation of the class of a star's spectrum, even in the case of stars of the eighth magnitude. This part of the Harvard labours should not be dismissed without reference to the remarkable *coup d'œil* of the spectra of stars in the *Pleiades*. It is impossible to look at it without the suggestion of a community of origin in the material and formation of this historic group. And the deduction of this cosmical fact is the result of the intelligent labour of a single hour! Altogether this valuable memoir indicates a very distinct advance of the application of photography to astronomical research.

"*Annuaire du Bureau des Longitudes.*"—Admiral Mouchez has herein given an interesting account of celestial photography from the time of the well-aimed but unsuccessful attempts of Nièpce and Daguerre, in 1839, to the superb results now being achieved at Paris by the brothers Henry. The labours of these latter *savants* are now happily so well known to the astronomical world that an account of them here would be superfluous. One of the most striking features in the photographic enlargements of the plates is the definite roundness and general neatness of the impressions of the stars; features which indicate the remarkable perseverance, or it may be termed the endurance, of the observer in the manual control of the driving clock during the usual exposure of an hour. For any purpose of exact measures this definiteness of outline is indispensable. On some of these plates there are traces of impressions of stars which may probably be regarded as of the sixteenth magnitude. In submitting these photographs to enlargements, and subsequent printing in some permanent material, such as a modification of printer's ink, there is at present an unavoidable loss of the faintest stars, amounting in general to about a magnitude and a half; this will apparently limit printed copies to about the fourteenth magnitude on Pogson's scale, and requires an exposure at present exceeding an hour. We believe it is the present proposition of the Paris astronomers to effect arrangements for the photography of the entire stellar regions to this extent of brightness. This scheme is much more extensive, and perhaps more ambitious, than that proposed by the American astronomer, and instead of its completion at two observatories, in less than a twelvemonth, will require the co-operation of eight or ten at least, extending the labour through four or five years. Indeed, if there be a duplication of the photographic plates—and this seems to be indispensable for securing reliable results—the time occupied in the work and the number of the observers employed must be further extended. But these are points, as already suggested, which must be submitted to the consideration of the convention at Paris, summoned by Admiral Mouchez, in April next.

In the *Annuaire* (page 785) there is a very interesting and instructive plate of highly magnified images of stars impressed on a photographic film. But impressions of this nature, and thus highly magnified, would be far too loose and scattered in

form to admit of micrometric measurement; they greatly differ in appearance from the round and definite and solid-looking formations submitted to measurement at Oxford; nevertheless they do afford a good idea of the mode in which the sensitised material is blackened and deposited. But it should be remembered that this form of actinised deposit was distinctly noticed and described by Bond some thirty years ago.

The direction of the valuable work so ably accomplished at the Paris Observatory will be seen from the following catalogue, taken from the last annual report of that institution. It includes forty-two large plates of the Milky Way and of other regions, viz. the neighbourhood of $\epsilon$ *Lyræ* and of *Vega*, showing after two hours' exposure, stars much feebler than the *debilissima* of Sir J. Herschel, and feebler than the sixteenth magnitude, some of which have probably not been seen before. Clusters in *Hercules* (two plates), in *Ophiuchus*, in *Perseus*, and more than six hundred double or multiple stars; short exposures of groups intended for micrometrical measurement, such as the *Pleiades*, *Præsepe*, and M. 23 *Ophiuchi*.

*Mr. Common's Article in the "Nineteenth Century."*—It is quite unnecessary to refer to the highly interesting particulars discussed in this paper with all the authority of a master in the art; it will be in the hands of all astronomers interested in the progress of their science.

In even this condensed reference to the advances in Celestial Photography, certainly established by Mr. Common, it is right to add that Mr. Roberts' photographs, which are in the possession of the Society, seem in some respects to have surpassed the *Orion* Nebula of that gentleman, as well as the *Pleiades* Group of MM. Henry.*

*The Parallax of* 61 *Cygni.*—So far, the foregoing records refer in the main to what may, without derogation or offence, be termed the pictorial or delineation-side of astronomical photography. We have already stated what the brothers Henry have been able to achieve in the way of celestial charts; possibly even more remarkable results have been accomplished by Mr. Common, who has produced a representation of the *Orion* Nebula surpassing, it may be, in accuracy and in minuteness of detail the united labours of Herschel and Rosse in England, and of Bond and Holden in the United States. One potential only of the new art remained still to be examined; can it be relied on as presenting an amount of accuracy in delicate micrometrical measurement equal to that derived from the use of the Equatoreal Telescope and the Heliometer? In the hands of Bond thirty years ago it did indeed furnish the means of measuring the relative positions of the components of such double stars as he could then photograph; but the important question remains, can it now, in its more important modern development, vie with

* See *Monthly Notices* for January 1887 and Admiral Mouchez's note on p. 813 of the Paris *Annuaire* for 1887.

the Heliometer in the determination of such minute quantities as are discussed in problems connected with Stellar Parallax? In a word, can it be relied on in the conduct of varying measures when they are extended through a series of many months and over hundreds of sensitised plates? There is reason to believe that a reply in the affirmative has been given to this crucial question by the very recent and successful determination of the Parallax of 61 Cygni at the University Observatory in Oxford. No less than eight independent determinations of the relative parallax of the two components of this star, in relation to four faint stars in their neighbourhood, present an accordance that was scarcely to be hoped for anterior to the result. A collateral advantage presented by this method consists in this, that the relative parallax is obtainable not merely in respect of four stars, but in respect of all the other stars upon the photographic plate. In this way the resulting mean becomes not merely relative parallax, but approaches the absolute. In the case of this particular star, the result of the computations is a parallax lying as a mean between those determined by Bessel, Auwers, and Ball.

Dr. Lohse, at Potsdam, has successfully applied the ordinary refracting telescope to the subject of Stellar Photography, and this he has done without separating the lenses of the object glass or the introduction of a subsidiary lens. It is stated that after one hour's exposure of the plate in the proper focal position, the faintest stars visible in the telescope to the eye are distinctly impressed on the photograph.

For information on the valuable and interesting work in Stellar Photography, now in process of execution under the direction of Dr. Gill, the reader is referred to the Report from the Royal Observatory at the Cape of Good Hope, printed in the present number of the *Monthly Notices*.

On taking a general survey of the foregoing records of the potency and astonishing progress of this new application of a recent art, placing the whole starry heavens as a picture in our hands, one's thoughts irresistibly turn to the existence of considerable groups and sections of learned men, who persuade themselves that astronomy, as a science, culminated in the researches of Lagrange and Laplace, and, as an art was worn out in the hands of Bessel and the Herschels. It has been still further affirmed that, amidst the modern developments and activities of other branches of knowledge, astronomy, whether as a science or an art, has ceased to possess human interest. An unprejudiced perusal of the above and similar records is sufficient to indicate the utter unreasonableness of the latter thought. It would be far nearer to the truth to affirm that at the present hour, both as an art and a science, astronomy possesses the elasticity and the hopeful enterprise of robust youth. It would be a still securer belief to rest assured that as long as the human mind retains its experience of the past, and its incentives to curiosity

in respect of the future, no true art can ever culminate, and no true science can become effete. C. P.

*The Velocity of Light.*

Professor Newcomb has published in the second volume of the important series of astronomical papers prepared for the use of the *American Ephemeris and Nautical Almanac* his measures of the velocity of light made during the years 1880–82. Chapter I. is devoted to an interesting historical account of previous researches on the subject. The method adopted in the present investigation was that of Foucault, with certain modifications, principally in the optical arrangements. The form of the apparatus and the conditions of the problem are fully described in Chapters II. and III.

The revolving mirror consisted of a rectangular prism of polished steel, the vertical faces of which were nickel-plated, and thus formed the surface from which the light was reflected. At each end of the prism a fan-wheel was fixed, and the mirror was driven by an air blast playing upon the opposite side of each wheel. For the fixed mirror, two concave mirrors, each about 40 c.m. in diameter, were used side by side, so as to obviate any slight displacements from a single mirror, and in order to strengthen the return image. The radius of the curvature of the mirror was about 3000 mètres.

In 1880 the locations of the mirrors were at a distance apart of 2550·95 mètres, but in 1881 and 1882 the longer distance of 3721·21 mètres was employed.

All the observations are given in detail, and the results are very fully discussed on the hypotheses (1) that the motion of the revolving mirror is uniform in running; (2) that the figure of the mirror remains invariable; and (3) that the changes in direction of the reflected ray are correctly measured by the angular motion of the receiving telescope around the axis of the revolving mirror. This discussion shows certain systematic differences in the results obtained for each year, the final result depending entirely upon the measures of 1882.

Professor Newcomb gives the concluded velocity of light in vacuo as 299860 kilomètres, with a probable error of $\pm 30$ kilomètres. Combining this result with Nyrén's value of the constant of aberration, the corresponding solar parallax is $8''\cdot794$.

To this very important investigation are appended some interesting researches by Mr. Michelson on the velocities of white and coloured light in air, water, and carbon disulphide. The conclusions (which the author advances with great diffidence), are that the velocity of light in carbon disulphide is to that in air as 1·00 to 1·76, with an uncertainty of two units in the second place of decimals; and that orange-red light travels in carbon disulphide from 1 to 2 per cent. faster than greenish-blue light.

## *The Visual Solar Spectrum in* 1884.

The Royal Society of Edinburgh has published during the year (*Transactions*, vol. xxxii. Part III.) a remarkable study of the solar spectrum by the Astronomer Royal for Scotland. The work was undertaken by him with the leading idea of ascertaining whether the spectroscope would offer any evidence as to changes in the absorption of our atmosphere resulting from the great volcanic outbursts of 1883, and especially from that of Krakatoa. The conditions at Edinburgh being unfavourable for work of the kind, Professor Smyth selected as his observing station a country-house called "Kurn Hattin," about two miles to the north of Winchester, and proceeded thither early in June 1884. He was provided with a fine Rowland grating of 14438 lines to the inch, and had attached a recording apparatus of special form to his spectroscope, which enabled him to record with great rapidity the positions of the lines observed. It was his intention to form three complete and independent charts of the entire spectrum, and this design he was enabled to carry out in its entirety, despite very unpropitious weather, by the assistance of Colonel Knight. The results of his observations are given in sixty plates, giving five views of the spectrum, the first two being reproductions of the work of some standard observer for the sake of comparison, the maps of Ångström and Fievez being used for the most part, and the last three the three successive "Winchester" spectra. All are reduced to the same scale, which is not the usual one of wave length, but of wave frequency to the British inch; the wave length expressed in tenth-mètres is however added. The part of the spectrum shown in any plate is clearly and agreeably indicated by tinting it of one homogeneous colour, approximately the average colour of the region; whilst the relative intensities of the dark lines are indicated by variations in their heights. The wave lengths are not absolute determinations, but differential only, Ångström's values for the principal lines being assumed throughout. Even so, however, there are occasionally, as Professor Smyth himself points out, some striking discrepancies between the positions of lines as recorded in the three chartings; but when the unfavourable conditions, under which the greater part of the work was carried out, are remembered, and the great rapidity with which the observations were made—nearly the whole of the second spectrum, extending from A to *h*, and embracing about 7000 lines, having been mapped in three mornings, 1865 lines being laid down in three hours—the general accord between the three independent maps is very remarkable. Perhaps not the least important result of the work will have been to

show how rapidly a detailed chart of the entire visible spectrum can be formed when a suitable recording apparatus is employed.

With regard to the immediate purpose of the charts, the principal result Professor Smyth deduces from them is, that the visual solar spectrum in 1884 showed a marked general dulling at the two ends, the red and violet, "such as should arise from the upper air, being at that time overcharged with opaque dusty particles." The evidence for the existence of fresh atmospheric lines was much less satisfactory, although a strong line, wave length 4733 tenth-mètres, was repeatedly observed at Winchester, which is not shown on Fievez's chart. The repetition of such a survey of the spectrum as Professor Smyth has here carried out, at intervals of two or three years apart, would probably lead to the detection of changes in it which could scarcely fail to be instructive. In the meantime, Professor Smyth has supplied a valuable record of its appearance in the summer of 1884.

E. W. M.

*Papers read before the Society from February 1886 to February 1887.*

1886.

ar. 12. Phenomena of the satellites of *Jupiter* and *Saturn*, and occultations of stars by the Moon, observed at Mr. Edward Crossley's Observatory, Bermerside, Halifax, in the year 1885, with the 9⅓-inch Cooke Refractor. J. Gledhill.

Occultation of *Aldebaran*, 1886, Jan. 16. Professor R. S. Ball.

Occultations observed at Beloit, Wisconsin, in 1884–85. J. Tatlock.

On the orbit of 40 ($o^2$) *Eridani*. J. E. Gore.

The great shower of Andromedes, 1885. T. W. Backhouse.

Some new red and orange-red stars. Rev. T. E. Espin.

Observation of the conjunction of *Saturn* and $\mu$ *Geminorum*. J. Tebbutt.

Additional remarks on the periodic time of $\alpha$ *Centauri*. E. B. Powell.

Occultations of stars by the Moon and phenomena of *Jupiter's* satellites observed at Stonyhurst in the year 1885. Rev. S. J. Perry.

The new star in *Orion*, photometrically and spectroscopically observed at the Oxford University Observatory. Professor C. Pritchard.

Observations of comets *d* 1885 (Fabry), and *e* 1885 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Note on some recently published spectroscopic observations. E. W. Maunder.

Observations of the new star in *Andromeda*, made at Mr. Wigglesworth's Observatory with 15·5-inch Cooke Refractor. J. G. Lohse.

pril 9. Note on the radiation of meteors. W. F. Denning.

On some suggested improvements in the practical working of M. Loewy's new method of determining the elements of astronomical refraction. David Gill.

On the orbit of $\alpha$ *Centauri*. E. B. Powell.

April 9. Observations of the phenomena of *Jupiter's* satellites, made at the Adelaide Observatory with the 8-inch Cooke Equatorial in the year 1885. Communicated by C. Todd.

The magnitude of $\eta$ *Argûs* in March 1886. W. H. Finlay.

On the protuberances visible in the spectrum with a narrow slit. E. L. Trouvelot.

Observations of occultations of the stars by the Moon, 1884–85, and of the IVth satellite of *Jupiter*, 1885, made at the Radcliffe Observatory, Oxford. Communicated by E. J. Stone.

On the semi-diameter of *Venus*. W. G. Thackeray.

The nebulæ in the *Pleiades*. A. A. Common.

Note on the observations for coincidence of the collimators through the cube of the Transit Circle at the Royal Observatory, Greenwich. H. H. Turner.

Observations of Comets *d* 1885 (Fabry), and *e* 1885 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

May 14. Note on M. Trouvelot's paper on protuberances visible in the spectrum with a narrow slit. E. W. Maunder.

Introduction to a catalogue of the colours of 1730 stars. W. S. Franks.

Observations of the companion of *Sirius* made at the Dearborn Observatory, Chicago. Prof. G. W. Hough.

*Jupiter's* third satellite in transit, April 11, 1886. W. F. Denning.

Observations of the new star in *Orion*. J. E. Gore.

The meteor shower of Halley's Comet. W. F. Denning.

On the proper motion of twenty-nine telescopic stars. J. L. E. Dreyer.

Note on a remarkable sun spot. B. J. Hopkins.

Observations of Comets *d* 1885 (Fabry), *e* 1885 (Barnard), and *a* 1886 (Brooks), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

The fourth satellite of *Jupiter* during superior conjunction on the night of April 5, 1886. E. J. Spitta.

Comparisons of certain southern star catalogues. A. M. W. Downing.

June 11. Micrometric observations of Nova *Andromedæ*, made at the Dunsink Observatory. Sir R. S. Ball.

Observations of the satellites of *Saturn* and *Mars*, and of the companion of *Sirius*, made at the U.S. Naval Observatory, Washington. Professor Asaph Hall.

On the orbit of $\zeta$ *Sagittarii*. J. E. Gore.

On Delaunay's method of calculating the terms of long period in the motion of the Moon. E. Neison.

11. Observations of Comet Fabry (*d* 1885), made at Grahamstown, Cape of Good Hope. L. A. Eddie.

On Kepler's problem. R. Bryant.

Observations of comet *a* 1886 (Brooks), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

On the asserted foreshortening of the inner side of the penumbra of spots when near the Sun's limb. Rev. F. Howlett.

On the superiority of zinc and steel pendulums. T. Buckney.

Ephemeris of the satellites of *Saturn*, 1886–87. A. Marth.

The northern hemisphere of *Mars*. N. E. Green.

On a remarkable instance of the detection of distortion in a photographic film, measured for the purpose of stellar parallax. Professor C. Pritchard.

Supplementary measures of the magnitudes of a zone of stars near the equator for reference as standards of magnitude in lieu of *Polaris*. Professor C. Pritchard.

Note with respect to the invention of the achromatic telescope. A. C. Ranyard.

12. Observations of the variable star *R Carinæ* from Sept. 1883 to April 1886. J. Tebbutt.

Observations of Comets *d* 1885 (Fabry), *e* 1885 (Barnard), *c* 1886, and I. 1886 (Brooks), made at the Sydney Observatory. Communicated by H. C. Russell.

Observations of Comets 1877, I., II., III., VI.; 1880, III.; 1882, III.; and 1884, III., made at the Dun Echt Observatory with the 15-inch Refractor. Dr. R. Copeland.

Sextant observations of Fabry's Comet. Capt. J. Campbell, and Capt. D. S. Cromarty.

Observation of *Calliope*, made at the Observatory, Düsseldorf. [Extract from a letter to Mr. Stone.] Dr. R. Luther.

Ephemeris of the satellite of *Neptune*, 1886–87. A. Marth.

On the orbit of Σ 1757. J. E. Gore.

A reply to Mr. Neison's strictures on Delaunay's method of determining the planetary perturbations of the Moon. G. W. Hill.

On the orbit of Comet II., 1883, discovered by Mr. Ross. Lieut.-Gen. J. F. Tennant.

On the determination of the Radius Vector in the absolute orbit of the planets. Dr. H. Gyldén.

Observations of the phenomena of *Jupiter's* Satellites made at Windsor, New South Wales, in the year 1886. J. Tebbutt.

Nov. 12. Newall's occultor. R. S. Newall.
Distribution of Meteor Streams. W. F. Denning.
Note on the star $\gamma$ *Equulei*. G. Knott.
Reply to certain questions raised before the Royal Astronomical Society at the meeting on 1886, March 12, concerning the matter detailed in a paper entitled "Bright lines in stellar spectra." O. T. Sherman.
Note on Photographs of Stars in *Cygnus*, taken in August 1886. Isaac Roberts.
Note on two photographs of the Nebulæ in the *Pleiades*, taken in October 1886. Isaac Roberts.
Ephemeris for physical observations of *Jupiter*, 1887. A. Marth.
On evidence with respect to the form of the area of the heavens from which the meteors of November 27, 1885, appeared to radiate. A. C. Ranyard.
Observations of Comet *f* 1886 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.
Bands observed in the spectra of sun spots at Stonyhurst Observatory. Rev. A. Cortie.
Observations of Comets made at Mr. Wigglesworth's Observatory with the 15·5-inch Cooke Refractor. J. G. Lohse.

Dec. 10. Formulæ for binary stars. J. E. Gore.
Observations of Comets Winnecke and Finlay, 1886, made with the 11½-inch equatorial and filar micrometer at the Sydney Observatory. Communicated by H. C. Russell.
Ephemeris of the satellites of *Uranus*, 1887. A. Marth.
Second supplement to Sir J. Herschel's general catalogue of nebulæ and clusters of stars. J. L. E. Dreyer.
Note on an erratic meteor. B. J. Hopkins.
On Hartwig's Nova *Andromedæ*. Dr. R. Copeland.
Mr. Sherman's observations of bright lines in stellar spectra. E. W. Maunder.
Observations of Comet *f* 1886 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Jan. 14. Spectroscopic observations of the motion of stars in the line of sight made at the Temple Observatory, Rugby. G. M. Seabroke.
On the best device for revolving a dome. D. P. Todd.
Meteors with curved paths. W. F. Denning.
A new variable star in *Puppis*. A. S. Williams.
On the orbit of 14 (*i*) *Orionis* (OΣ 98). J. E. Gore.
Occultation of $\gamma$ *Virginis*, 1886, Dec. 18. F. C. Penrose.
Photographs of nebulæ in *Orion* and in the *Pleiades*. Isaac Roberts.

Jan. 14. Note on the electric illumination of the Armagh Refractor. J. L. E. Dreyer.

Occultation of *Aldebaran*, 1887, Jan. 6. Rev. S. J. Johnson.

Observations of Comet *f* 1886 (Barnard), made at the Royal Observatory, Greenwich. Communicated by the Astronomer Royal.

Sextant observations of Comets Fabry and Barnard, 1886. Capt. W. G. Browne and Capt. W. Randall.

On the variability of the spectrum of $\gamma$ *Cassiopeiæ*. Dr. R. Copeland.

Note on an application of photography to the determination of stellar parallax. Professor C. Pritchard.

Observations of the Moon made at the Radcliffe Observatory, Oxford, during the year 1886, and a comparison of the results with the tabular places from Hansen's Lunar Tables. E. J. Stone.

Mean Right Ascensions of *Polaris*, *Cephei* 51 (Hev.), $\delta$ *Ursæ Minoris* and $\lambda$ *Ursæ Minoris* for the year 1887, from the Radcliffe Observations of the years 1880 to 1886. E. J. Stone.

Spectroscopic results for the motions of stars in the line of sight obtained at the Royal Observatory, Greenwich, in the year 1886. No. X. Communicated by the Astronomer Royal.

Observations of occultations of stars by the Moon, and of phenomena of *Jupiter's* Satellites, made at the Royal Observatory, Greenwich, in the year 1886. Communicated by the Astronomer Royal.

*List of Public Institutions, and of Persons who have contributed to the Library, &c. since the last Anniversary.*

Her Majesty's Government.
Her Majesty's Government in Australia.
Her Majesty's Government in India.
The Lords Commissioners of the Admiralty.
The Norwegian Government.
British Association for the Advancement of Science.
British Horological Institute.
Geological Society of London.
Institute of Civil Engineers.
Meteorological Office.
Photographic Society of Great Britain.
Physical Society of London.
Royal Asiatic Society of Great Britain.
Royal Geographical Society.
Royal Institution of Great Britain.
Royal Meteorological Society.
Royal Observatory, Greenwich.
Royal Society of London.
Royal United Service Institution.
Society of Arts.
University College, London.
Zoological Society of London.
Armagh Observatory.
Belfast Natural History and Philosophical Society.
Birmingham Philosophical Society.
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Edinburgh, Royal Observatory.
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Leeds Philosophical and Literary Society.
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Oxford, Radcliffe Observatory.
Rugby School Natural History Society.
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Adelaide, Royal Society of South Australia.
Amsterdam, Royal Academy of Sciences.
Baltimore, Johns Hopkins University.
Batavia, Royal Society of Natural History.
Berlin, Royal Academy of Sciences.
Berlin, Royal Observatory.
Berlin, Royal Prussian Geodetic Institute.
Berne University.
Bombay Branch of the Royal Asiatic Society.
Bombay, Government Observatory.
Bordeaux Observatory.
Bordeaux, Society of Physical and Natural Sciences.
Boston, American Academy of Arts and Sciences.
Boston Scientific Society.
Brisbane, Queensland Branch of the Geographical Society of Australasia.
Brussels, Royal Observatory.
Buda-Pesth, Hungarian Academy of Sciences.
Calcutta, Asiatic Society of Bengal.
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Delft, École Polytechnique.
Dijon, Academy of Sciences.
Geneva, Society of Physics and Natural History.
Georgetown College.
Göttingen, Royal Society of Sciences.
Haarlem, Musée Teyler.
Halle, Imperial Leopold-Caroline Academy.
Harvard College Astronomical Observatory.
Helsingfors, Society of Sciences of Finland.
Hong Kong Observatory.
Kalocsa, Haynald Observatory.
Kasan, Imperial University.
Leipzig, Astronomische Gesellschaft.
Leipzig, Royal Society of Sciences of Saxony.
Madison, Washburn Observatory of the University of Wisconsin.
Madras Observatory.
Madrid Educational Institute.
Madrid, Royal Academy of Sciences.
Mannheim Observatory.
Melbourne Observatory.
Melbourne, Patent Office.
Mexico, Scientific Society.
Moncalieri Observatory.
Montreal, Royal Society of Canada.

Moscow, Imperial Society of Naturalists.
Moscow Observatory.
Munich, Royal Bavarian Academy of Sciences.
Munich, Royal Observatory.
Naples, Academy of Sciences.
Natal Observatory.
New York, Columbia College.
Paris, Academy of Sciences.
Paris, Bureau des Longitudes.
Paris, Dépôt Général de la Marine.
Paris, École Polytechnique.
Paris, International Committee of Weights and Measures.
Paris, Mathematical Society of France.
Paris Observatory.
Paris, Philomathic Society of France.
Philadelphia, American Philosophical Society.
Philadelphia, Franklin Institute.
Potsdam, Astrophysical Society.
Prague Observatory.
Pulkowa Observatory.
Rio de Janeiro Observatory.
Rome, Central Meteorological Office.
Rome, Italian Spectroscopic Society.
Rome, National Library.
Rome, Accademia Pontificia dei Lincei.
Rome, Reale Accademia dei Lincei.
St. Petersburg, Imperial Academy of Sciences.
San Fernando Observatory.
Santiago Observatory, Chile.
Sydney, Government Observatory.
Tacubaya Observatory, Mexico.
Taschkend Observatory.
Tasmania, Royal Society.
Tokio University.
Toronto, Canadian Institute.
Toulouse, Academy of Sciences.
Turin, Italian Meteorological Society.
Turin, Observatory of the Royal University.
Turin, Royal Academy of Sciences.
Upsala, Royal Society of Sciences.
Vienna, Imperial Academy of Sciences.
Vienna, Imperial Observatory.
Virginia, Leander McCormick Observatory.
Washington, Office of the American Ephemeris.
Washington, Philosophical Society.
Washington, Smithsonian Institution.
Washington, United States Chief Signal Office.
Washington, United States Coast and Geodetic Survey.
Washington, United States Naval Observatory.
Yale College Observatory.

Yokohama, Seismological Society of Japan.
Zurich, Central Meteorological Institute.
Zurich, Society of Natural History.
Editors of the American Journal of Science.
Editors of the American Journal of Mathematics.
Editor of the Astronomical Register.
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# ADDRESS

*Delivered by the President, Mr. J. W. L. Glaisher, on presenting the Gold Medal of the Society to Mr. G. W. Hill.*

The Council have awarded the Gold Medal to Mr. George William Hill for his researches upon the Lunar Theory; and it now becomes my duty to lay before you the grounds of this award.

The investigations of Mr. Hill's which the Council have had principally in view are contained in the memoir "On the Part of the Motion of the Lunar Perigee, which is a Function of the Mean Motions of the Sun and Moon," which was published by him ten years ago at Cambridge, Mass. The merits of Mr. Hill's treatment of this question are such, that, even if this memoir stood by itself as his sole contribution to physical astronomy, the Council would have felt themselves justified in recognising its value by the highest mark of appreciation which it is in their power to confer. Mr. Hill's object in this memoir is to determine with absolute accuracy the motion of the Moon's perigee, on the assumption that the Sun's orbit has no eccentricity, that the Moon's motion takes place in the plane of the ecliptic, and that the eccentricity of the Moon's orbit is indefinitely small: in other words, to determine an absolutely accurate value of that part of $c$ which depends upon $m$ alone.

It will be remembered that this quantity $c$, which expresses the mean motion of the Moon's perigee, has played an important part in the early history of the theory of gravitation. Newton proved a general proposition from which it follows that the disturbing action of the Sun necessarily produces a continual advance of the Moon's perigee; and he gave a numerical example which has been generally regarded as his calculation of the theoretical amount of this advance in the case of the Moon.* The mean monthly progression obtained in this example

* Lib. I., Sect. ix., Prop. xlv., Cor. 2. The concluding words "Apsis lunæ est duplo velocior circiter" have been quoted in support of the view that the motion of the lunar apsides is the question considered in this corollary. These words were, however, intended to have exactly the opposite meaning. This can be shown by comparing the three editions of the *Principia*; further confirmation is also afforded by certain papers lately found by Professor Adams in the Portsmouth collection of Newton manuscripts.

is 1° 31′ 28″, whereas the observed monthly progression of the Moon is about double this amount. This discrepancy formed one of the chief impediments to the acceptance of the Newtonian system, and an interval of sixty years elapsed before theory and observation were brought into agreement. This was effected by Clairaut, who was on the point of publishing a new hypothesis with respect to the law of gravitation, when it occurred to him to extend the approximation to the third order. He found that the numerical value of the new term was nearly as great as that of the term of the second order. The supposed Newtonian value of $1-c$ was $\frac{3}{4}m^2$, and Clairaut's additional term was $\frac{225}{32}m^3$; amounting to about $\frac{7}{10}$ of the previous term. Thus the circumstance which had for some time seemed almost fatal to the Newtonian theory became one of its strongest confirmations.

The series of which the first two terms were calculated by Newton and Clairaut has been continued by Delaunay as far as the term involving $m^9$. The progression of the terms is such as we might anticipate from the first two; the coefficients increase rapidly; and, though the smallness of $m$ causes the terms to diminish, their rate of convergence is very slow.

The problem which Mr. Hill set before himself for solution was the exact determination of the numerical value of the quantity represented by this series. The development in powers of $m$, besides being extremely difficult and laborious to obtain, was from its nature ill adapted for the calculation of $c$ with all the precision that could be desired. Mr. Hill accordingly had recourse to an entirely different method of obtaining the numerical value of this quantity.

Starting with the general equations of motion, he finds the differential equations which determine the inequalities having the first power of the lunar eccentricity as a factor. By a remarkable series of analytical transformations, the solution of these differential equations is made to depend upon that of a single differential equation of the peculiarly simple and elegant form

$$\frac{d^2 w}{d\tau^2} + \Theta w = 0,$$

where $\tau$ denotes the mean angular distance between the Sun and Moon, and $\Theta$ can be developed in a periodic series of the form

$$\Theta_0 + \Theta_1 \cos 2\tau + \Theta_2 \cos 4\tau + \text{\&c.}$$

If $\Theta_1$, $\Theta_2$, &c. are to a considerable degree smaller than $\Theta_0$, an approximate solution of the equation is

$$w = K\epsilon^{ic\tau} + K'\epsilon^{-ic\tau},$$

where $i$ denotes $\sqrt{-1}$, K and K′ are arbitrary constants, and $c$ denotes the square root of $\Theta_0$. When the additional terms are

taken into account, the effect is to modify this value of c, and also to add to w new terms of the form

$$e^{\pm i(c+2p)\tau}.$$

We may, therefore, take as a particular integral

$$w = \Sigma_p b_p e^{i(c+2p)\tau};$$

and by substituting this value of w in the differential equation, we obtain an infinite system of algebraical equations, each consisting of an infinite number of terms. This system of equations suffices to determine the ratios of all the coefficients $b_1$, $b_2$, &c., to one of them, as $b_0$, and also the value of c, the ratio of the synodic to the anomalistic month.

If from these equations we eliminate all the $b$'s, we obtain a symmetrical determinant of an infinite order involving c, which, when equated to zero, determines this quantity. This equation Mr. Hill writes

$$\mathfrak{D}(c) = 0.$$

A first approximation to the value of c is $\sqrt{\Theta_0}$; a second and much more accurate approximation is given by

$$c = \sqrt{1 + \sqrt{(\Theta_0 - 1)^2 - \Theta_1^2}}.$$

This very simple expression for an approximate value of the motion of the Moon's perigee is obtained by neglecting quantities of the order $m^5$ in the determinantal equation $\mathfrak{D}(c) = 0$. The numerical values of $\Theta_0$ and $\Theta_1$ are

$$\Theta_0 = \quad 1\cdot1588439$$
$$\Theta_1 = -0\cdot0570440,$$

and by substituting these values in the above expression for c we find

$$c = 1\cdot0715632$$

whence

$$1 - c = 1 - c(1 - m) = 0\cdot008591.$$

This is about $\frac{1}{60}$ in excess of the value 0·008452 given by observation; the difference being mainly due to the neglect of the inclination of the lunar orbit.*

* Mr. Hill has also given the following curious formula, which is obtained by neglecting quantities of the order $m^7$ :

$$\tan\theta = \frac{\pi\Theta_1^2}{4\sqrt{\Theta_0}(\Theta_0 - 1)},$$

then c is given by the equation

$$\cos\pi c = \frac{\cos(\pi\sqrt{\Theta_0} - \theta)}{\cos\theta}.$$

This formula, though it involves the same coefficients $\Theta_0$ and $\Theta_1$ as the approximate formula given in the text, is much more exact. It gives $1 - c$ = 0·00857210, which is correct to the sixth decimal. See the reprint of Mr. Hill's paper in the *Acta Mathematica*, vol. viii. (1886). p. 28.

In order to deduce a perfectly accurate value of c from the equation $\mathfrak{D}$ (c) = o, Mr. Hill proceeds to consider the nature of the roots of this equation. He points out that if it is satisfied by $c = c_0$ it must necessarily be satisfied also by all quantities of the form $\pm (c_0 + 2p)$, $p$ being an integer; and he is thus led to put

$$\mathfrak{D}(c) = A\{\cos(\pi c) - \cos(\pi c_0)\}$$

The constant A is next determined, and the determinant $\mathfrak{D}$ (c) is replaced by a new determinant $\nabla$ (c), derived from it by the equation

$$\nabla(c) = \frac{1}{A}\mathfrak{D}(c)$$

so that

$$\nabla(c) = \cos(\pi c) - \cos(\pi c_0).$$

This equation is true identically. Putting c = o, and subtracting, we thus find

$$\cos(\pi c) = 1 - \nabla(0),$$

as the subscript zero may now be omitted. This very remarkable equation is equivalent to $\mathfrak{D}$ (c) = o, and gives by its solution the value of c, which we are seeking; the particular root to be chosen being that to which $\sqrt{\Theta_0}$ is a first approximation.

Mr. Hill makes still one further change in order to replace $\nabla$ (o) by a determinant in which all the terms in the principal diagonal shall be unity. Denoting this new determinant by (o), the final form of the equation giving c is expressed in the form:

$$\frac{\sin^2(\frac{1}{2}\pi c)}{\sin^2(\frac{1}{2}\pi\sqrt{\Theta_0})} = \square(0),$$

where $\square$ (o) denotes the very elegant determinant

$$\left|\begin{array}{ccccccc}
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdots & 1, & -\frac{\Theta_1}{4^2-\Theta_0}, & -\frac{\Theta_2}{4^2-\Theta_0}, & -\frac{\Theta_3}{4^2-\Theta_0}, & -\frac{\Theta_4}{4^2-\Theta_0}, & \cdots \\
\cdots & -\frac{\Theta_1}{2^2-\Theta_0}, & 1, & -\frac{\Theta_1}{2^2-\Theta_0}, & -\frac{\Theta_2}{2^2-\Theta_0}, & -\frac{\Theta_3}{2^2-\Theta_0}, & \cdots \\
\cdots & -\frac{\Theta_2}{0^2-\Theta_0}, & -\frac{\Theta_1}{0^2-\Theta_0}, & 1, & -\frac{\Theta_1}{0^2-\Theta_0}, & -\frac{\Theta_2}{0^2-\Theta_0}, & \cdots \\
\cdots & -\frac{\Theta_3}{2^2-\Theta_0}, & -\frac{\Theta_2}{2^2-\Theta_0}, & -\frac{\Theta_1}{2^2-\Theta_0}, & 1, & -\frac{\Theta_1}{2^2-\Theta_0}, & \cdots \\
\cdots & -\frac{\Theta_4}{4^2-\Theta_0}, & -\frac{\Theta_3}{4^2-\Theta_0}, & -\frac{\Theta_2}{4^2-\Theta_0}, & -\frac{\Theta_1}{4^2-\Theta_0}, & 1, & \cdots \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot
\end{array}\right|$$

In the lunar theory the quantity $\Theta_p$ is of the $2p^{\text{th}}$ order. Mr. Hill, with great analytical skill developes this determinant as

far as terms of the twelfth order. It is with reluctance that I abstain from reproducing the remarkable expression which he obtains. It occupies eight lines, and consists of terms of the fourth order, the eighth order, and the twelfth order. It is exactly the same result as would be obtained if, starting with the equation $\square(c) = 0$, and assuming $c = \sqrt{\Theta_0}$ as a first approximation, we expanded the function $\sin^2(\frac{1}{2}\pi c)$ in ascending powers and products of the coefficients $\Theta_1$, $\Theta_2$, &c.

Passing now to numbers, Mr. Hill puts

$$n = 17325594''\cdot06085$$
$$n' = 1295977''\cdot41516$$

and deduces the value of $\Theta_0, \Theta_1, \ldots \Theta_7$ to 15 places of decimals, and by substituting these values in his expression for $\square(0)$ he obtains finally

$$c = 1\cdot07158\ 32774\ 16012,$$

whence

$$1 - c = 0\cdot00857\ 25730\ 04864.$$

By a process of substitution in the original equations a verification of this value of $c$ is afforded.

It is interesting to compare Mr. Hill's value with the value given by Delaunay's expression in powers of $m$, viz.:

$$1 - c = \frac{3}{4}m^2 + \frac{225}{32}m^3 + \frac{4071}{128}m^4 + \frac{265493}{2048}m^5 + \frac{12822631}{24576}m^6$$
$$+ \frac{1273925965}{589824}m^7 + \frac{71028685589}{7077888}m^8 + \frac{32145882707741}{679477248}m^9.$$

Using the values of $n$ and $n'$ given above, the numerical values of the terms of this series are

| | | | |
|---|---|---|---|
| $m^2$ | 0·00419 6429 | $m^6$ | 0·00009 1395 |
| $m^3$ | 0·00294 2798 | $m^7$ | 0·00002 8300 |
| $m^4$ | 0·00099 5700 | $m^8$ | 0·00000 9836 |
| $m^5$ | 0·00030 3577 | $m^9$ | 0·00000 3468 |

giving 0·00857 1503 as the value of $1-c$.

By comparing this value with Mr. Hill's it appears that the sum of the remainder of Delaunay's series is 0·0000 1070, which is rather less than might be inferred by induction from the terms of the series itself. In spite of the labour expended by Delaunay in computing eight terms of this series, the result does not suffice to give correctly the first four significant figures of $1-c$. On the other hand, in Mr. Hill's process, the highest terms included in the calculation of the expression for $\square(0)$ are only of the twelfth order, and yet they suffice to give $c$ correctly to the fifteenth decimal. As well as can be judged by induction, it

would be necessary, Mr. Hill thinks, to prolong Delaunay's series as far as $m^{27}$ in order to obtain an equally precise result.

I am sensible that a presidential address does not in general afford a suitable opportunity for mathematical exposition; but I have felt that on the present occasion the novelty and intrinsic interest of the mathematical methods employed justify me in the attempt I have made to give a brief sketch of the remarkable investigation by which Mr. Hill has arrived at his numerical value of $c$. It will be observed that the problem of the determination of this quantity is attacked entirely *de novo*, from first principles, by a peculiar analytical method devised for this especial purpose. The object is to obtain the numerical value of that part of $c$ which depends upon $m$ only; and this object is attained with a degree of precision that sets the problem at rest for ever.

The mathematical process is very peculiar. Not only is it quite different from any of the methods with which the lunar theory is associated, but it even displays novelty from the point of view of the pure mathematician. I am not aware that actual use has ever been previously made of an infinite determinant in any of the applications of mathematics, or that the development of such a determinant (by proceeding outwards from its central constituent, as it were) has ever been the subject of mathematical investigation. One cannot admire too highly the courage and skill with which Mr. Hill has dealt with the new mathematical questions to which his methods have led him. Not only has he availed himself of the modern instruments which the advance of mathematics had placed within his reach, but he has successfully grappled with the novel mathematical difficulties which have accompanied their use. The calculation of the determinants formed from the $3^2$, $5^2$, $7^2$, &c. constituents symmetrically disposed with respect to the central constituent of an infinite determinant, and the consideration of the convergency of these determinants, are questions of mathematical interest which are well deserving of study on their own account, apart from the practical applications in which, as Mr. Hill has shown, the results of such investigations are required.

Although the memoir of Mr. Hill's to which I have so far confined myself was the first in order of publication of his papers on the Lunar Theory, its true chronological place is subsequent to his "Researches on the Lunar Theory," which appeared in the first volume of the "American Journal of Mathematics" (1878). In the calculation of the quantities $\Theta_0$, $\Theta_1$, $\Theta_2$, &c. (which depend only upon the case of no eccentricities), Mr. Hill derived his numerical data from an investigation of his own to be subsequently published. This investigation is contained in the "Researches," which may be regarded as introductory to the memoir relating to the motion of the perigee.

At the beginning of the "Researches" Mr. Hill divides the periodic developments of the lunar co-ordinates into classes of

terms, and proposes to treat the following five classes of inequalities:

1. Those which depend only on the ratio of the mean motions of the Sun and Moon.
2. Those which are proportional to the lunar eccentricity.
3. Those which are proportional to the sine of the lunar inclination.
4. Those which are proportional to the solar eccentricity.
5. Those which are proportional to the solar parallax.

He also promises a general method by which these investigations may be extended so as to cover the whole ground of the Lunar Theory.

Only two chapters of the "Researches" were published: the first relates to the general differential equations of motion, and the second to the first of the five classes of inequalities mentioned above. The memoir on the motion of the perigee belongs to the second class; so that we are in possession of Mr. Hill's general methods and their application to two out of the five classes of inequalities.

Passing over Mr. Hill's able discussion of the general equations of motion, I proceed to give a brief sketch of the analytical method by which he treats the first two classes of inequalities.

If the axis of $x$ rotate with uniform angular velocity $n'$, so as always to pass through the Sun, the differential equations of motion in the ordinary form are

$$\frac{d^2x}{dt^2} - 2n'\frac{dy}{dt} + \left(\frac{\mu}{r^3} - 3n'^2\right)x = 0,$$

$$\frac{d^2y}{dt^2} + 2n'\frac{dx}{dt} + \frac{\mu}{r^3}y \qquad = 0.$$

Mr. Hill transforms these equations as follows:

Denoting $\surd(-1)$ by $i$, let

$$\nu = n - n',$$

$$\mathrm{m} = \frac{n'}{\nu}, \quad \kappa = \frac{\mu}{\nu^2};$$

also let

$$\tau = \nu(t - t_0), \qquad \zeta = \epsilon^{i\tau},$$

and put

$$u = x + iy, \qquad s = x - iy,$$

$$\mathrm{D} = -i\frac{d}{d\tau} = \zeta\frac{d}{d\zeta};$$

so that

$$\mathrm{D}\zeta^p = p\zeta^p;$$

then $u$ and $s$ satisfy the differential equations:

$$\left\{D^2 + 2mD + \tfrac{3}{2}m^2 - \frac{\kappa}{(us)^{\frac{3}{2}}}\right\}u + \tfrac{3}{2}m^2 s = 0,$$

$$\left\{D^2 - 2mD + \tfrac{3}{2}m^2 - \frac{\kappa}{(us)^{\frac{3}{2}}}\right\}s + \tfrac{3}{2}m^2 u = 0,$$

each of which may of course be derived from the other by changing the sign of $i$.

These equations determine rigorously all the parts of the lunar co-ordinates which depend only on the ratio of the mean motions of the Sun and Moon and the lunar eccentricity.

Now let

$$u = \Sigma a_p \zeta^{2p+1},$$

$$s = \Sigma a_{-p-1} \zeta^{2p+1},$$

$p$ having all integral values from $+\infty$ to $-\infty$.

The most simple method of obtaining the coefficients $a_p$ is by substituting these values of $u$ and $s$ in the differential equations and equating coefficients. The presence of the factor $\frac{\kappa}{(us)^{\frac{3}{2}}}$ is a great additional source of complication in carrying out this process, and it is therefore desirable to eliminate it. This Mr. Hill effects by means of a first integral of the differential equations, and he at length obtains, as the final form of the equations to be employed,

$$D^2(us) - Du \,.\, Ds - 2m(uDs - sDu) + \tfrac{9}{4}m^2(u+s)^2 = C,$$

$$D(uDs - sDu - 2mus) + \tfrac{3}{2}m^2(u^2 - s^2) = 0.$$

By substituting the values of $u$ and $s$ in these differential equations, a system of algebraical equations connecting the a's is obtained from which they may be determined either numerically or algebraically in terms of m.

It will be noticed that tne differential equations in this final form are such that in no case is it necessary to multiply together more than two infinite series.

The system of algebraical equations obtained by equating coefficients is infinite in number, and each equation contains an infinite number of terms involving the products of two a's.

It is found that $a_p$ is of the $2p^{\text{th}}$ order with respect to m; and, in solving the equations, only the terms of lowest order are in the first instance retained. The equations thus curtailed give the first four terms of the expansions in powers of m of $a_1$, $a_{-1}$, $a_2$, $a_{-2}$, &c. Thus $a_1$ and $a_{-1}$ are affected with errors of the sixth order; $a_2$ and $a_{-2}$ with errors of the eighth order, and so on.

One of the great advantages of the method consists in the ease and rapidity with which the approximations can be extended; for we have only to return to the original curtailed equations and augment each of them by the terms necessary to carry the

approximation four orders higher; we then substitute in the new terms the values obtained from the first approximation, and in the old we determine what changes are produced by employing the more exact values instead of the first approximations. A repetition of this process carries the approximation four orders higher still, and so on.

Mr. Hill gives in full the equations which determine the a's correctly to quantities of the thirteenth order inclusive; * and he deduces from them the expansions of

$$\frac{a_{\pm 1}}{a_0}, \ldots \frac{a_{\pm 4}}{a_0}.$$

in powers of m as far as $m^9$.

From these expansions the values of $r \cos v$ and $r \sin v$, as series proceeding by cosines and sines of multiples of $2\tau$, are easily deduced by means of the equations

$$r \cos v = \Sigma a_p \cos 2p\tau$$
$$r \sin v = \Sigma a_p \sin 2p\tau,$$

the summations extending to infinity both ways. The coefficients in these series are given as far as the ninth order inclusive in powers of $\mathfrak{m}$, where

$$\mathfrak{m} = \frac{m}{m - \frac{1}{3}m}.$$

Not only does Mr. Hill give these coefficients in a literal form, which he afterwards reduces to numbers, but he gives also the direct numerical calculation, employing numerical values from the outset in the equations of condition. This latter method is found to be, as we should suppose, far less laborious than the literal development of the coefficients in powers of a parameter.

The series given by previous mathematicians are unsuitable for the determination of the motion of satellites having long periods of revolution about their primaries; and Mr. Hill is accordingly led to apply his method, which is available in such cases, to the exact determination of the expressions for $r \cos v$ and $r \sin v$ in terms of $\tau$ when $m = \frac{1}{10}, \frac{1}{9}, \frac{1}{8}, \ldots \frac{1}{3}$. For moons of much longer lunations the method is not practicable, and it is necessary to resort to mechanical quadratures. The motion is

* The final differential equations only suffice to determine the ratios of the a's to any one of themselves, as $a_0$. For the actual determination of $a_0$ in terms of $\mu$ and $n$ recourse must be had to one of the original differential equations, and in this way the value of $a_0$, viz.

$$a_0 = \left(\frac{\mu}{n^2}\right)^{\frac{1}{3}}\left[1 - \tfrac{1}{6}m^2 + \tfrac{1}{3}m^3 + \tfrac{407}{2304}m^4 - \&c. \right]$$

is determined as far as the term involving $m^9$ inclusive. It is from the values of the coefficients $a_p$, which depend upon m alone, that the values of $\Theta_0$, $\Theta_1$, $\Theta_2$, &c., which were required in finding the motion of the perigee, were derived by Mr. Hill.

determined in this manner in the cases of $m = 2$ and $m = 1{\cdot}78265$. The latter value of m corresponds to a lunar orbit (relative to the moving axes) having cusps at the points of quadratures.

Brief as has necessarily been the preceding account of the mathematical processes employed by Mr. Hill, I hope that it has been sufficient to give an idea of their character. It is not often that the points of novelty in an application of mathematics to a well-known problem in one of the older sciences are so distinctive as to admit of explanation within a moderate compass. The present investigation is so exceptional in this respect that I have ventured to reproduce the main lines of the mathematical procedure.

Two obvious deviations from established custom at once attract attention: first, the use of rectangular instead of polar coordinates; and secondly, the introduction of the imaginary quantity $i$.

With regard to the choice of coordinates, it is known that in the elliptic theory the rectangular coordinates of a planet relative to a central body can be developed in series of sines and cosines, in which the coefficients are Besselian functions, although the longitude and latitude are far from having such simple expressions, and in fact are not even finitely expressible in terms of Besselian functions. If this be true in the elliptic theory, how much more likely, Mr. Hill asks, is a similar result to be true when the complexity of the problem is increased by the consideration of the disturbing forces? Thus there is reason to believe that the coefficients of the periodic terms in the developments of the rectangular coordinates are less complex functions of their parameters than in the case of polar coordinates. Another important advantage is afforded by the fact that when expressed in rectangular coordinates the differential equations assume purely algebraic forms, while in polar coordinates they involve circular functions.

The quantity $i$ is used in order to avoid the multiplications of series of sines and cosines, and to reduce all the quantities to an algebraic form. It is at once apparent that the choice of $e^{\tau i}$ or $\zeta$ as independent variable greatly simplifies the expression of the series and the analysis in general. Having had occasion myself, in a very different branch of mathematics, to multiply together infinite series of sines and cosines, I have found the advantage of making a similar substitution, and I can bear testimony to the analytical simplicity and regularity produced in such processes by the substitution of

$$\Sigma_{-\infty}^{\infty} A_p z^p \quad \text{and} \quad \frac{1}{i}\Sigma_{-\infty}^{\infty} B_p z^p$$

for

$$A_0 + 2\Sigma_1^{\infty} A_p \cos 2p\theta \quad \text{and} \quad 2\Sigma_1^{\infty} B_p \sin 2p\theta$$

$A_{-p}$ and $B_{-p}$ being supposed equal to $A_p$ and $-B_p$ respectively.

It may be remarked that the vector $u$ or $x+iy$ is a symbol to which a clear conception is now attached, and also that in the equation

$$x+iy=\Sigma \mathfrak{a}_p \zeta^{2p+1}$$

the quantities $\mathfrak{a}_0$, $\mathfrak{a}_1$, $\mathfrak{a}_{-1}$, &c. are the radii of actual epicycles. The geometrical picture which this equation represents is that of a pure epicyclic system.

Mr. Hill employs the parameter $\mathfrak{m}$, which is equal to $\dfrac{m}{1-m}$, in place of $m$. Although $\mathfrak{m}$ is slightly larger than $m$ it is found that in the series proceeding by powers of $\mathfrak{m}$ the coefficients are much smaller than in the case of those proceeding by powers of $m$. and that the series converge more rapidly. The quantity $\mathfrak{m}$, which has been mentioned above, was specially determined in order to render the series giving the $\mathfrak{a}$'s as convergent as possible.

The superiority of the expansions in powers of $\mathfrak{m}$, both in convergence and simplicity of coefficients, is evident by comparing the values of $\dfrac{\mathfrak{a}_1+\mathfrak{a}_{-1}}{\mathfrak{a}_0}$ and $\dfrac{\mathfrak{a}_1-\mathfrak{a}_{-1}}{\mathfrak{a}_0}$, which when expressed in powers of $\mathfrak{m}$ assume the forms

$$-\{\mathfrak{m}^2+\tfrac{1}{2}\mathfrak{m}^3-\tfrac{2}{9}\mathfrak{m}^4+\tfrac{1}{36}\mathfrak{m}^5-\&c.\}$$

and

$$\tfrac{11}{8}\mathfrak{m}^2+\tfrac{7}{4}\mathfrak{m}^3+\tfrac{5}{72}\mathfrak{m}^4-\tfrac{11}{36}\mathfrak{m}^5+\&c.$$

respectively; the corresponding series, as given by Plana and Delaunay, being

$$-\{m^2+\tfrac{19}{6}m^3+\tfrac{131}{18}m^4+\tfrac{383}{27}m^5+\&c.\}$$

and

$$\tfrac{11}{8}m^2+\tfrac{59}{12}m^3+\tfrac{893}{72}m^4+\tfrac{2855}{108}m^5+\&c.$$

With regard to the general question of parameters, it is pointed out that the large numerical coefficients which occur in Delaunay's expansions are probably due to the choice of $m$ as parameter, and that they might be very much diminished if a more suitable parameter were employed. Further, it is not necessary to use the same parameter throughout, and it may well happen that different parameters may be advantageously employed in the investigation of different classes of inequalities. Examples of the extraordinary increase of convergence which can be affected by a change of parameter are afforded by logarithmic series, and, in a much more striking form, by the various expansions of the elliptic functions. Mr. Hill, however, gives it as the result of his experience that no useful results are obtained by experimenting with the present known developments, and that in every case the proper parameter must be derived from *à priori* considerations suggested by the course of the integration.

Passing now to general considerations, it will be noticed that Mr. Hill obtains the integrals of his differential equations by the method of indeterminate coefficients. This is the method which would seem to offer the best chance of discovering the law of the series. A further advantage of this method, which is not possessed by Delaunay's, is that it affords either the numerical values of the coefficients or the literal development in powers of a parameter.

Of all the general methods of treating the Lunar Theory as a whole, Delaunay's is by far the most elegant and complete, and is likely to become the classic method in this subject. When, however, the object is to investigate only a certain class of inequalities, it is not without its disadvantages; for example, even if we only desire to obtain the inequalities whose coefficients depend solely upon $m$, we are nevertheless obliged to develop the disturbing function $R$ to all powers of $e$. Again, in Delaunay's method, the number of variables is doubled in order that all the differential equations may be of the first order; but when the coefficients are determined by direct substitution in the differential equations their order is immaterial. The two main characteristics which distinguish Mr. Hill's general analytical treatment of the lunar theory are the expression of the equations in terms of the coordinates instead of in terms of the elements, and the diminution of the number of variables and differential equations at the expense of increasing the order of the latter.

Immediately after the publication of Mr. Hill's first memoir (on the motion of the Moon's perigee), Professor Adams communicated a paper to the *Monthly Notices* (vol. xxxviii., p. 43), in which, after bearing testimony to the high merits of Mr. Hill's investigation, he mentions that he has been led to dwell thus particularly on this subject because his own researches in the lunar theory have followed in some respects a parallel course. Professor Adams states that he has long been convinced that the most advantageous way of treating the lunar theory is, first, to determine with all desirable accuracy the inequalities which are independent of $e$, $e'$ and $\gamma$, and then in succession to find the inequalities which are of one dimension, two dimensions, and so on with respect to those quantities. Thus, the coefficient of any inequality in the Moon's coordinates would be represented by a series arranged in powers and products of $e$, $e'$ and $\gamma$; and each term in this series would involve a numerical coefficient which is a function of $m$ alone, and which admits of calculation for any given value of $m$ without the necessity of developing it in powers of $m$. This method is particularly advantageous when we wish to compare our results with those of an analytical lunar theory such as Delaunay's, in which the eccentricities and the inclination are left indeterminate, since each numerical coefficient could be compared separately with its analytical development in powers of $m$. As it is only the series proceeding by powers of $m$ in

)elaunay's theory which have a slow rate of convergence, it s probable that all the sensible corrections required by Delaunay's oefficients would be found among the terms of low order in $e$, $e'$ nd $\gamma$.

Professor Adams proceeds: "The differential equations which vould require solution in these successive operations after the letermination of the inequalities independent of eccentricities nd inclination would be all linear and of the same form.

"It is many years since I obtained the values of these last-amed inequalities to a great degree of approximation, the oefficients of the longitude expressed in circular measure, and hose of the reciprocal of the radius vector, or of the logarithm f the radius vector, being found to ten or eleven places of lecimals.

"In the next place, I proceeded to consider the inequalities f latitude, or rather the disturbed value of the Moon's co-rdinate perpendicular to the ecliptic, omitting the eccentricities s before, and taking account only of the first power of $\gamma$.

"In this case the differential equation for finding $z$ pre-ents itself naturally in the form to which Mr. Hill reduces, with o much skill, the equations depending on the first power of the ccentricity of the Moon's orbit.

"In solving this equation I fell upon the same infinite deter-ninant as that considered by Mr. Hill, and I developed it in a imilar manner in a series of powers and products of small uantities, the coefficient of each such term being given in a inite form.

"The terms of the fourth order in the determinant were hus obtained by me on December 26, 1868. I then laid aside he further investigation of this subject for a considerable time, ut resumed it in 1874 and 1875; and on December 2 in the atter year I carried the approximation to the value of the leterminant as far as terms of the twelfth order, or to the same xtent as that which has been attained by Mr. Hill. I have also ucceeded in reducing the determination of the inequalities of ongitude and radius vector which involve the first power of the unar eccentricity to the solution of a differential equation of the econd order; but my method is much less elegant than that of Mr. Hill.

"Immediately after Mr. Hill's paper reached me I wrote to im expressing my opinion of its merits, and telling him what I ad done in the same direction; and I received from him a very ordial and friendly letter in reply.

"The equation which I had obtained by equating the above-nentioned determinant to zero differed in form from Mr. Hill's; nd on making the reductions required to make the two results mmediately comparable, I found that there was an agreement etween them except in one term of the twelfth order. On xamining my work I found that this arose from a simple error f transcription in a portion of my work, and that when this had

been rectified my result was in entire accordance with Mr. Hill's. The calculations by which I have found the value of the determinant are very different in detail from those required by Mr. Hill's method, and appear to be considerably more laborious."

The differential equation which determines $z$, the Moon's coordinate perpendicular to the equator, is

$$\frac{d^2z}{dt^2}+\left(\frac{\mu}{r^3}+\frac{m'}{r_1^3}\right)z=0.$$

This equation thus presents itself originally (as mentioned by Professor Adams) in the same form,

$$\frac{d^2w}{d\tau^2}+\Theta w=0,$$

as that to which Mr. Hill succeeds in reducing the equations upon which the inequalities involving the first power of the lunar eccentricity depend.

Professor Adams puts

$$\frac{\mu}{r^3}+\frac{m'}{r_1^3}=(n-n')^2\left\{q^2+2\Sigma_1^\infty q_p\cos 2p(n-n')t\right\}$$

and Mr. Hill puts

$$\Theta=\Theta_0+\Theta_1\cos 2\tau+\Theta_2\cos 4\tau+\&c.$$

The same determinant is, therefore, reached in both cases, and there is no great difference in the notation. Professor Adams's form of the developed value of the determinant is given on p. 47 of volume of the *Monthly Notices* referred to. By means of this developed expression, the value of $g$, which stands to the node in the same relation that $c$ does to the perigee, is found to fifteen places of decimals. I may mention that in this paper Professor Adams also gives the numerical values of the terms in the expansions of $g-1$ and $c-1$ both in powers of $m$ and of $\mathrm{m}$. In each case the development in powers of $\mathrm{m}$ is much the more advantageous; and he states that he has found that a similar advantage results from the employment of $\mathrm{m}$ instead of $m$ in the development of the Moon's periodic inequalities.

Before considering in a more general light the inferences that we may draw from the similarity of the researches of Professor Adams and Mr. Hill, I should like to draw attention to the fundamental character of Mr. Hill's infinite determinant in the lunar theory, and possibly also in other applications of mathematics.

The differential equation

$$\frac{d^2w}{d\tau^2}+\Theta w=0.$$

may be regarded as a canonical form.* Mr. Hill was led to it by

* Riccati's equation and several other well-known equations are reducible to this form, which has been much studied; but, so far as I know, the case in which $\Theta$ is a periodic series has not been considered.

considering the motion of the perigee, Professor Adams by considering the motion of the node. It is probable that many other inequalities can be made to depend upon the solution of an equation of this form. The form of $\Theta$, viz.,

$$\Theta_0 + \Theta_1 \cos 2\tau + \Theta_2 \cos 4\tau + \&c.,$$

where $\Theta_p$ is of the $2p$th order, is very general; and so also is the method of solution by indeterminate coefficients.

The determinant in question, therefore, possesses considerable mathematical interest of its own, and its properties and development seem likely to admit of a wide application in mathematical researches in which periodic functions are involved.

The fact that the work carried out independently by Professor Adams and Mr. Hill should have run so much upon the same lines, and have so much actually in common, affords strong evidence that it is in this direction that we must look, in the present condition of the lunar theory, for any further important advances. It is almost impossible to study the writings to which I have referred without becoming impressed by this feeling. Mr. Hill puts the matter very clearly when he points out that the great majority of the mathematicians who have worked at the lunar theory have had before them, as their ultimate aim, the construction of tables; that is to say, they have viewed the problem from the standpoint of practical astronomy rather than of mathematics. This accounts for the restricted choice of variables and parameters. "Again," proceeds Mr. Hill, "their object compelling them to go over the whole field, they have neglected to notice many minor points of great interest to the mathematician, simply because the knowledge of them was unnecessary for the formation of tables. But the developments having now been carried extremely far, without completely satisfying all desires, one is led to ask whether such modifications cannot be made in the processes of integration, and such coordinates and parameters adopted, that a much nearer approach may be had to the law of the series, and at the same time their convergence augmented."

In recent years it has come to be generally believed that a worker had but little chance of performing useful service in the lunar theory unless he was prepared to make it the study of his life. The belief also has been prevalent that the mathematical portion of the treatment of the subject has been worked out, and that there was no scope for the display of mathematical skill or the employment of modern mathematical methods. Until some great discovery should change the face of the whole subject, it has seemed likely that patience and diligence in traversing with greater care the old lines, and extending still further developments already carried to a wonderful extent, would be all that was required to perfect the theory. Considering, on the other hand, the attractiveness of the new and rapidly progressing

branches of pure mathematics, and of many recent applications of mathematics to physical science, it is scarcely to be wondered at that so few of the younger generation of mathematicians should have included the lunar theory within their subjects of research. The papers of Mr. Hill's which I have described, and certain recent papers of Professor Adams's, have invested the lunar theory with a new mathematical interest, and have shown that in the treatment of the special problems included in the subject there is an ample opportunity not only for the application of existing mathematical methods, but even for the discovery of new ones. These papers show also that it is possible for the mathematician to confine himself to these special problems without attempting to cover the whole ground of the lunar theory. I hope that this is the dawn of a new day in the history of the lunar problem, and that, now that the whole territory has been mapped out by Plana and Delaunay, it will be found that the special investigations offer a tempting field to the mathematician. So far from the subject having been exhausted by the general methods which have been applied to it as a whole, I believe that the future will show that they have but cleared the ground and disclosed to view the objects to which mathematical investigation may with the greatest advantage be directed.

I have now described, though necessarily in a very imperfect manner, Mr. Hill's mathematical researches upon special problems in the lunar theory, the originality and peculiar value of which the Council have been especially desirous of recognising by the award of their medal. I can refer but briefly to Mr. Hill's other important contributions to physical astronomy, most of which, however, have been already noticed in our Annual Reports.

The American *Journal* contains two other papers of his. The first of these, in the fourth volume, is a short note on "Hansen's General Formulæ for Perturbations," in which an equation of Hansen's is expressed in a form which is not only more simple, but also more convenient for computation. The second, in the sixth volume, is entitled "On Certain Possible Abbreviations in the Computation of the Long-Period Inequalities of the Moon's Motion, due to the Direct Action of the Planets." Hansen has characterised the calculation of the coefficients of these inequalities as extremely difficult; but Mr. Hill finds that if the shortest methods are followed this is no longer the case. In this characteristic paper, Mr. Hill, following the principles which, as we have seen, have guided him in all his work, attacks the question from the very beginning by a direct analytical investigation. He thus obtains finally, not only a new method for the actual computation of the inequalities, but also some results of more purely mathematical interest.

Three elaborate memoirs have been published by Mr. Hill among the astronomical papers prepared for the use of the *American Ephemeris and Nautical Almanac* (i) "On Gauss's

Method of Computing Secular Perturbations, with an Application to the Action of *Venus* on *Mercury*" (1881); (ii) "Determination of the Inequalities of the Moon's Motion, which are produced by the Figure of the Earth: a Supplement to Delaunay's Lunar Theory" (1884); (iii) "On Certain Lunar Inequalities, due to the Action of *Jupiter*, and discovered by Mr. E. Neison" (1885).

The object of the first of these papers is to reproduce in a form practically useful for astronomers the results given by Gauss in his celebrated memoir, "Determinatio Attractionis &c." In the original memoir the method is not presented in such a manner that it admits of easy application to an actual case. In this paper Mr. Hill places Gauss's process within the reach of any computer possessed of ordinary mathematical knowledge. Gauss's investigation is reproduced in full, with the addition of the details necessary for its application; and, finally, the formulæ themselves, in the shape in which they are required by the practical calculator, as well as the necessary tables of elliptic integrals, are given. As an example, the computation of the secular perturbations of *Mercury*, produced by the action of *Venus*, are worked out; the final results agreeing very closely with those of Leverrier. It is to be hoped that this paper may have the effect of bringing into more general practical use Gauss's very beautiful and perfect method.

The second memoir is described by the author in its title as a supplement to Delaunay's Lunar Theory At the time of Delaunay's death the inequalities caused by the disturbing action of the Sun were complete; but the small effects produced by the spheroidal figure of the Earth, and other minor portions of the subject, were untouched. Mr. Hill's object in this memoir is to supplement Delaunay's great work by determining, in a literal form, all the inequalities of the Moon which arise from the figure of the Earth to the same degree of algebraical approximation as that adopted by Delaunay in determining the solar perturbations—that is, to terms of the seventh order inclusive. The value of a constant which enters into the coefficients and depends upon the figure of the Earth is determined by an elaborate discussion of numerous pendulum experiments; and by the substitution of the values of $m$, $e$, $e'$, $\gamma$ and this constant, the numerical values of the coefficients are deduced. The whole of this elaborate investigation seems to have been carried out with great skill and care. I should mention that, in his treatment of the subject, Mr. Hill adopts in principle the usual method of applying Delaunay's theory to the determination of the lunar inequalities which are due to causes other than the Sun's action, and that there is possibly a slight imperfection in this method. It is probable, however, that the differences due to this cause are insensible.

In the third of the memoirs referred to Mr. Hill effects the determination of the coefficients of two lunar inequalities,

due to the action of *Jupiter*, to which Mr. Neison drew attention in vol. xxxvii. of the *Monthly Notices*. Mr. Hill's values of these coefficients do not agree with those assigned to them by Mr. Neison. In the case of the second inequality Mr. Hill's value amounts to only about one-tenth of Mr. Neison's.

It is nine years since Mr. Hill undertook for the office of the *American Ephemeris and Nautical Almanac* an investigation of the motions of *Jupiter* and *Saturn*, with the view of constructing tables of these two planets. From its commencement this great work has occupied nearly the whole of his time; and, even if no hindrance occurs, it must continue to do so for the next three or four years. It is well known that the theory of *Saturn* is in an unsatisfactory state, Leverrier's tables failing to represent adequately the observations. A special interest therefore attaches to these new investigations which have been carried out by means of Hansen's very refined methods. The work has so far progressed very satisfactorily. The final expressions for the co-ordinates of the two bodies, together with the details of a preliminary comparison of them with observations made for the purpose of ascertaining what corrections the perturbations might need on account of errors in the provisionally assumed elements, were published last year in the "Astronomische Nachrichten" (Nos. 2,705–2,706). When these investigations, in which the approximations are carried to a much greater extent than in any previous treatment of the subject, are completed, the whole will form by far the largest and most complete investigation of the kind that has yet been performed on the American continent.

It is doubtless due to the engrossing character of this work that only two chapters of the "Researches on the Lunar Theory" were published. There is abundant evidence that Mr. Hill's researches must have been extended far beyond those given in these two chapters at the time when his new labours deprived him of the leisure necessary for completing and preparing them for press; and I trust that when the Theory and Tables of *Jupiter* and *Saturn* shall have been published, Mr. Hill may be enabled to resume his mathematical researches at the point at which their publication ceased, and to carry out his original intention to its full extent.

*The President then, delivering the Medal to the Foreign Secretary, addressed him in the following terms:*

Dr. Huggins,—May I ask you in transmitting this medal to Mr. Hill to assure him of our high appreciation of the value of his contributions to physical astronomy, and to express to him our earnest hope that his life may long be spared, and that he may have health and strength to complete the splendid work upon which he is now engaged, and to enrich our science still further by his mathematical researches.

The meeting then proceeded to the election of the Officers and Council for the ensuing year, when the following Fellows were elected:—

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J. W. L. Glaisher, Esq., M.A., F.R.S.

*Vice-Presidents.*

Arthur Cayley, Esq., M.A., LL.D., D.C.L., F.R.S., Sadlerian Professor of Pure Mathematics, Cambridge.
W. H. M. Christie, Esq., M.A., F.R.S., Astronomer Royal.
The Earl of Crawford and Balcarres, F.R.S.
Edwin Dunkin, Esq., F.R.S.

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H. H. Turner, Esq., B.A., B.Sc.

# MONTHLY NOTICES

OF THE

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J. W. L. Glaisher, M.A., F.R.S., President, in the Chair.

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*On the Determination of the Radius Vector in the Absolute Orbit of the Planets.* By Prof. Hugo Gyldén, Director of the Observatory, Stockholm.

The method of variation of constants, given by Lagrange, forms the theoretical foundation of astronomy at the present time. In cases where the mathematical problem cannot be rigorously solved we have, by its help, not only been enabled to compute the movements of the heavenly bodies by successive approximations, but have also succeeded in stating the nature of the motions in an intelligible manner. We seem also to have attained to something more precise than a mere rule for the computation of the effect of mutual attraction within definite intervals of time. The way in which this method has been hitherto applied in investigations on the theory of the movements of the heavenly bodies was not, however, in all respects the most appropriate for giving that general view of the laws of movement which should not be absent from a comprehensive scientific solution of the problem in question. The slight amount of success which results from the application of this method is explained by the fact that, if the approximations are carried out in a straightforward manner, they lead to developments in series according to powers of the time, and these series do not converge for any arbitrary magnitude of the variable; so that it is difficult to judge of the convergence of the approximations even when the development in powers of the time has been avoided by certain artifices.

It is well known that the method of variation of constants allows us a certain discretion; for a number of the equations from which the variations of the elements are to be computed can be fixed on at pleasure, and an arbitrary number of solutions can be found for the differential equations which, from a formal point of view, are distinct from one another, and which together contain a sufficient number of arbitrary constants to give us the place and velocity of a heavenly body at a given moment of time. In the application of this method to the planetary theory it has, until recently, been attempted to satisfy this condition as to the place and velocity of the planet by giving to the co-ordinates and to their first differentials with respect to the time, the same form in the later approximations as in the first.

The values, which in the first approximation appear as constants of integration, become in the later stage functions of the time, which must be evaluated step by step. Under these circumstances the orbits of the planets are regarded as Keplerian ellipses, whose elements, however, vary from instant to instant. But the variations of the elements cannot be regarded from so simple a point of view; little more can be said in description of them than that they are small in small intervals of time, but that if the time be taken sufficiently great they may become so considerable that the original ellipse is quite unrecognisable. The motion, the nature of which is thus intelligibly described, holds good strictly for a very short time; it can, however, be retained without actual practical inconvenience during several decades of years—perhaps for several centuries. However, the representation of the motion of the heavenly bodies, indicated above, is not sufficient from a scientific point of view, where it is desired to regard the phenomenon as independent of shortness or length of time; for the condition, that the co-ordinates and their differentials shall have the same form as in Kepler's theory of planetary motion, does not repose on a circumstance which should *à priori* give it the preference over all other methods. If actual analytical difficulties did not stand in the way, that condition ought to be replaced by another which would be appropriate to represent the nature of the planetary movements more completely than has hitherto been the case. A result of this would certainly be that a number of conceptions appropriate to Keplerian astronomy would be replaced by others. As may be however conjectured without analysis, the practical rules for computing the places of the planets would undergo very little alteration.

For many years then I have been convinced of the necessity of replacing the present point of view of the planetary theory by another which shall correspond in its actual features with the phenomenon of planetary motion during any arbitrary period. The conception of an absolute orbit and of absolute elements has now been established in consequence of the labour which I have devoted to this subject. The absolute orbit gives the path

of the actual motion very closely, so that the departure from exactness of the place computed in this orbit always remains of the order of the disturbing forces, and never assumes the character of a secular variation. In contrast with the elements of the osculatory or mean ellipse, which undergoes considerable variation under the influence of the secular disturbances, the elements of the absolute orbit are absolute constants, which are not subject to secular variations, otherwise than that the longitude is changed by the motion of the planet, of the apses, and of the nodes of its orbit.

Hence, the longitude must be given for a definite epoch. The three modular elements on which the mean distance, the excentricity, and the inclination depend, are, on the other hand, absolutely invariable, and serve for any moment of time whatever. For the representation of the co-ordinates in the absolute orbit I make use of certain functions which depend on the disturbing masses, but which do not vanish with them, but become constants corresponding to elliptic elements. For this reason I call these *the elementary functions*, and the individual terms, out of which these are formed, are the *elementary terms*.

The elementary terms have a form which is easily to be recognised; they are periodic, and their periods are either very long compared with the periodic time, form (A), or differ very little from that period, form (B). In the course of the developments, however, terms make their appearance which have the same form as the elementary terms, but differ from them in that they vanish with the disturbing masses. Such terms I call *subelementary terms*, and I say that they are of the first order when they involve, as a factor, the first power of a disturbing mass, and of the second order when they involve the square of a disturbing mass, or the product of two masses, &c. With reference to the excentricity, or to the constants which determine its magnitude, the elementary terms are of various orders, and the same holds with respect to the inclination. I reckon as of the first class an elementary term which contains the first power of a modulus of the excentricity; and of the second class terms which contain the squares or products in two dimensions of these moduluses, and so on.

It may be here pointed out that the terms of the form (A), whose periods are very long, belong to an even class, and the terms of the form (B) to an uneven class. If the succession of approximations is not appropriately arranged, terms may make their appearance in which the disturbing masses appear as divisors. Such terms must, of course, vanish from the result if the approximations are in general to converge and to lead to a real result. The appearance of terms of this kind always shows that the method in application, or the fundamental system of differential equations, was not the most appropriate; for the operations which lead to the vanishing of these terms are usually very troublesome, and the numerical results are always inexact,

because they arise from the differences of larger quantities. Terms which involve the disturbing masses as divisors I call *hyperelementary* terms. It would have been desirable that this name should not be required; but as such terms may appear, and as it would be easy to give equations of perturbation which necessarily lead to this complication of the problem, it is necessary to arm each method against the appearance of such terms. If no care is taken that the hyperelementary terms should not appear, or should not be made to vanish easily, the method in use, and the differential equations on which it is based, are certainly inappropriate. Also, if it cannot be proved that the hyperelementary terms must disappear, the conclusions derived from the method are of course untenable.

I have already published in several places investigations on the theory of the absolute orbit, or sketches of such investigations; in the following paper I shall show the connection of this theory with that of the variation of constants. This will afford the best means of finding points of comparison with the former theory of the motion of the heavenly bodies, the basis of which is furnished by the laws of Kepler. In place, however, of a complete comparison it must suffice to submit only the equation of the radius vector to an examination from this point of view; for this equation is especially characteristic of the new method of considering the subject.

At the time $t$, let $r$ be the true radius vector, and $v$ the true longitude in the orbit.

In the complete development of the theory of the absolute orbit, I do not usually make $r$ dependent on $v$, but on an argument $v_0$, which differs from $v$ by a magnitude of the order of the disturbing force. For the present purpose, however, this difference is altogether unimportant, and we shall, therefore, always write $v$ instead of $v_0$. In place of $r$ I now introduce a new function $\rho$, defined by

$$r = \frac{p}{1+\rho},$$

where, however, $p$ must not be regarded as constant, but has the signification of an elementary function. It is easy to see that, in the elliptic theory, $p$ and $\rho$ have the following meanings, viz.:—

$$p = a(1-e^2); \quad \rho = e\cos(v-\varpi),$$

where $a$ is the mean distance, $e$ the excentricity, and $\varpi$ the longitude of perihelion.

I denote the radius vector in the absolute orbit by $(r)$, and put

$$(r) = \frac{p}{1+(\rho)}$$

finally I write

$$r = \frac{(r)}{1+\frac{(r)}{a}\xi}$$

So that

$$\frac{a}{r}-\frac{a}{(r)}=\xi\,;\ \rho-(\rho)=\frac{p}{a}\xi.$$

For the determination of $\rho$ a differential equation of the second order may be found, which may be written as follows:—

$$\frac{d^2\rho}{dv^2}+(1-\beta+X)\rho=R.$$

In this equation $\beta$ denotes a constant of the order of the perturbing forces, $X$ and $R$ functions of the same order of magnitude, which, however, for the present are not fully known. They contain, in fact, besides other unknown magnitudes, the function $\rho$.

If, however, we confine ourselves in the first approximation to the determination of the elementary terms of the first class, we may regard the functions $X$ and $R$ as known. After the determination of $\rho$ corresponding to these values of $X$ and $R$, we obtain more exact values of $X$ and $R$, and repeat therewith the determination of $\rho$. Thus these functions are obtained by successive approximations. We here remark that $X$ may in a certain sense be considered as arbitrary, for only those terms need be retained in $X$ which, on multiplication by $\rho$, produce subelementary and elementary terms in the subsequent approximation.

We may further remark that, if all terms which contain uneven powers of $\rho$ as factors are regarded as being collected in $X\rho$, both $X$ and $R$ (of course only in so far as they contain subelementary terms, or give rise to such) may be regarded as even functions of $\rho$.

In the above differential equation let us now substitute for $\rho$ the value

$$(\rho)+\frac{p}{a}\xi,$$

and, further, let us divide $R$ into two parts, $M$ and $N$, such that

$$R=M+N,$$

and that

$$\frac{d^2(\rho)}{dv^2}+(1-\beta+X)(\rho)=M$$

$$\frac{d^2}{dv^2}\left(\frac{p}{a}\xi\right)+(1-\beta+X)\frac{p}{a}\xi=N.$$

Since the functions $M$ and $N$ are still quite arbitrary, we can, in choosing them, satisfy a certain condition. The object of this condition is generally that one of the functions shall only contain terms of a certain form, whilst the other either does not contain such terms at all, or only in such a way as to annihilate terms of the same form which arise in the function to be determined.

Before going further we shall adduce some general considerations on the form of the integrals of a linear equation of the second order. Let the equation be

$$\frac{d^2y}{dv^2}+Xy=R. \quad \ldots \ldots \ldots \ldots \quad (1)$$

We assume that the particular integrals of the equation

$$\frac{d^2y}{dv^2}+Xy=0. \quad \ldots \ldots \ldots \ldots \quad (2)$$

are known. If these integrals are denoted by $y_1$ and $y_2$, and the constants of integration by $g$ and $h$, we have

$$y=gy_1+hy_2. \quad \ldots \ldots \ldots \ldots \quad (3)$$

The functions $y_1$ and $y_2$ may now be multiplied by arbitrary constant factors, concerning which we say that they must be chosen so as to fulfil the equation

$$y_1y_2'-y_2y_1'=1.$$

As is well known, the solution (3) may be extended so as to apply to the equation (1), if we regard the quantities $g$ and $h$ as functions of $v$ instead of as constants. These functions, however, fulfil their object if they satisfy only a single equation of condition, which we shall give immediately; hence they may be chosen in any infinite number of different ways, without causing equation (3) to cease to give the integral of equation (1). By differentiation of (3) we obtain

$$y'=gy_1'+hy_2'+y_1\frac{dg}{dv}+y_2\frac{dh}{dv},$$

whence

$$y''=gy_1''+hy_2''+y_1'\frac{dg}{dv}+y_2'\frac{dh}{dv}+\frac{d}{dv}\left(y_1\frac{dg}{dv}+y_2\frac{dh}{dv}\right).$$

If we add this to equation (3), after it has been multiplied by $X$, we obtain, by help of (1) and (2), the following:—

$$y_1'\frac{dg}{dv}+y_2'\frac{dh}{dv}+\frac{d}{dv}\left(y_1\frac{dg}{dv}+y_2\frac{dh}{dv}\right)=R \quad \ldots \ldots \quad (4)$$

and this is the single equation of condition, which must necessarily be satisfied, in order that the value (3) of $y$ may give us the complete integral of (1). The second condition, which must be assumed in order to obtain an actual determination of $g$ and $h$, may remain entirely arbitrary.

If we take as this second condition—

$$y_1\frac{dg}{dv}+y_2\frac{dh}{dv}=0,$$

we obtain—

$$y'=gy_1'+hy_2'.$$

In this case not only has the integral of equation (1) the same form as that of equation (2), but the same is also true of the first differential coefficients. We may understand the results of this determination by a very simple example.

Let us take—

$$X=1\,;\ R=\gamma\cos[(1-\sigma)v-B],$$

where $\gamma$ and $\sigma$ are small quantities of the order of the disturbing forces, where $\gamma$ further involves the excentricity as a factor, and where the quantity $B$ denotes an arbitrary constant.

Then it easily follows that—

$$y_1=\cos v\,;\ y_2=\sin v.$$

When these values are substituted in the formulæ—

$$\frac{dg}{dv}=-y_2R\,;\ \frac{dh}{dv}=y_1R$$

they lead to the following expressions:—

$$\frac{dg}{dv}=-\tfrac{1}{2}\gamma\{\sin(\sigma v+B)+\sin[(2-\sigma)v-B]\}$$

$$\frac{dh}{dv}=\ \tfrac{1}{2}\gamma\{\cos(\sigma v+B)+\cos[(2-\sigma)v-B]\}$$

It may be remarked that $g$ and $h$ contain terms of two kinds; the first is an elementary term of the form (A), the second, on the other hand, does not belong either to the form (A) or to the form (B). This circumstance involves an unnecessary complication of the functions $g$ and $h$, which may become extremely troublesome when we have to deal with continued approximations. The complication may, however, be avoided if we do not make the condition at our disposal as before, but make it so as to simplify the functions $g$ and $h$. I remark that by such a simplification the meaning of the function $y$ is unaltered, and only the meaning of the differential of $y$ is affected. The loss of simplicity in the meaning of this differential is, however, in many cases (for example, in the planetary theory) a very slight evil in comparison with the advantage which is gained by the simplification of the functions $g$ and $h$. Besides, the adoption of the above condition depends actually on the fact that this choice appears obvious, and that there is no other before us; it depends also on the circumstance that the Keplerian representation of the planetary motions can be retained unchanged, so that the disturbances may be regarded as small corrections which will exercise no characteristic influence on the representation of the motion.

We will now, however, set aside the condition chosen above, and will replace it by a more general one.

We write then—

$$y_1\frac{dg}{dv}+y_2\frac{dh}{dv}=-(\lambda)\,.\quad.\quad.\quad.\quad.\quad.\quad.$$

so that $(\lambda)$ is an arbitrary function of $v$. From equation (4) we then find—

$$y_1\frac{dg}{dv}+y_2\frac{dh}{dv}=R+\frac{d(\lambda)}{dv},$$

whence there results—

$$\left.\begin{aligned}\frac{dg}{dv}&=-y_2\left(R+\frac{d(\lambda)}{dv}\right)-y_2'(\lambda)\\ \frac{dh}{dv}&=\quad y_1\left(R+\frac{d(\lambda)}{dv}\right)+y_1'(\lambda)\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Before going further we will prove directly that the function $y$ may be made independent of the function $(\lambda)$ by the substitution of the values of $g$ and $h$, which result from the equations just found, in the equation (1).

For since—

$$\frac{d}{dv}\Big(y_2(\lambda)\Big)=y_2\frac{d(\lambda)}{dv}+y_2'(\lambda)$$

$$\frac{d}{dv}\Big(y_1(\lambda)\Big)=y_1\frac{d(\lambda)}{dv}+y_1'(\lambda),$$

we obtain—

$$g=g_0-y_2(\lambda)-\int y_2Rdv$$

$$h=h_0+y_1(\lambda)+\int y_1Rdv,$$

where $g_0$ and $h_0$ are constants of integration.

Hence, from equation (3) we obtain—

$$y=y_1\left(g_0-\int y_2Rdv\right)+y_2\left(h_0+\int y_1Rdv\right).$$

This is a value which is completely independent of the function $(\lambda)$, and hence it is the same which we should have found if we had made $(\lambda)=0$.

As we have full disposal over the function $(\lambda)$, we can choose it so that the functions $g$ and $h$ may be as simple as possible; for example, they may be made to contain only elementary terms of the form (A), and this is especially advantageous in the planetary theory. In every such definition the equation of condition (4) must, of course, be satisfied, so that it is not possible completely to attain the intended object for every value of $R$. As already remarked, the differential equation must, for this reason, be divided into two, and the intended object, that the functions $g$ and $h$ may have the forms referred to, must be kept in view. And, further, certain terms of the function $R$ must be retained whilst the others are carried over to the second equation. In the simple example considered above the matter is as follows:—the function $R$ has already the form corresponding to our intention, for we may write—

$$R=\Psi\cos v+\Phi\sin v$$

where—

$$\Psi=\gamma\cos(\sigma v+B);\quad \Phi=\gamma\sin(\sigma v+B).$$

If now the values $y_1 = \cos v$, $y_2 = \sin v$ are substituted in the equation of condition (4), that equation can be satisfied by equating to zero the coefficients of $\cos v$ and $\sin v$ separately.

Hence, there result the equations—

$$\frac{d^2g}{dv^2} + 2\frac{dh}{dv} = \Psi$$

$$\frac{d^2h}{dv^2} - 2\frac{dg}{dv} = \Phi$$

This system can be integrated very easily. For if, after multiplying the second by $i = \sqrt{-1}$, we add the two equations together, we obtain the following linear differential equation of the second order:—

$$\frac{d^2}{dv^2}(g+ih) - 2i\frac{d}{dv}(g+ih) = \Psi + i\Phi,$$

whence it follows that

$$\frac{d}{dv}(g+ih) = e^{2iv}\int (\Psi + i\Phi)e^{-2iv}dv.$$

From this formula we may compute $\frac{dg}{dv}$ and $\frac{dh}{dv}$, whence $g$ and $h$ may be found by a simple quadrature.

We remark that the process remains unaltered when the functions $\Psi$ and $\Phi$ retain any number of terms of the same form as those written above.

We now assume a somewhat more general form for the particular integrals $y_1$ and $y_2$, writing

$$y_1 = f(v)\cos v\,;\quad y_2 = f(v)\sin v,$$

where $f$ denotes an elementary function of the form (A). If now the form of the function $R$ be assumed to be the same as in the preceding case, and if the coefficients of $\cos v$ and $\sin v$ be separately equated to zero, we find from equation (4)

$$f(v)\frac{d^2g}{dv^2} + 2f(v)\frac{dh}{dv} + 2f'(v)\frac{dg}{dv} = \Psi$$

$$f(v)\frac{d^2h}{dv^2} - 2f(v)\frac{dg}{dv} + 2f'(v)\frac{dh}{dv} = \Phi.$$

Whence

$$\frac{d^2}{dv^2}(g+ih) - \left(2i - 2\frac{f'(v)}{f(v)}\right)\frac{d}{dv}(g+ih) = \frac{1}{f(v)}(\Psi + i\Phi).$$

From the integration of this equation we obtain

$$\frac{d}{dv}(g+ih) = -\frac{e^{2iv}}{[\quad}\int f(v)e^{-2iv}(\Psi + i\Phi)dv.$$

With this result our problem may be regarded as solved, for when $f(v)$, $\Psi$, and $\Phi$ are given, there is no formal difficulty in obtaining the expressions for $\frac{dg}{dv}$ and $\frac{dh}{dv}$, and hence also for $g$ and $h$.

We will now make a third assumption as to $y_1$ and $y_2$, the basis of an investigation similar to that carried out above. We shall now, however, go somewhat further, and take into consideration the function which was previously regarded as indeterminate. This function has an actual application in the planetary theory.

Suppose, then, that

$$y_1 = f(v)\cos(v+\theta)\,;\quad y_2 = f(v)\sin(v+\theta),$$

where $f$ has the same meaning as before, and $\theta$ denotes a function of $v$ which, besides one term multiplied by $v$, only contains elementary terms of the form (A).

On assuming for $R$ the same form as above we obtain, by comparison of the coefficients of $\cos v$ and $\sin v$ in the equation of condition (4), the results

$$f(v)\cos\theta\frac{d^2g}{dv^2} + f(v)\sin\theta\frac{d^2h}{dv^2} + 2\left[\sin\theta f'(v) + \left(1+\frac{d\theta}{dv}\right)f(v)\cos\theta\right]\frac{dh}{dv}$$
$$+ 2\left[\cos\theta f'(v) - \left(1+\frac{d\theta}{dv}\right)f(v)\sin\theta\right]\frac{dg}{dv} = \Psi$$
$$-f(v)\sin\theta\frac{d^2g}{dv^2} + f(v)\cos\theta\frac{d^2h}{dv^2} + 2\left[\cos\theta f'(v) - \left(1+\frac{d\theta}{dv}\right)f(v)\sin\theta\right]\frac{dh}{dv}$$
$$-2\left[\sin\theta f'(v) + \left(1+\frac{d\theta}{dv}\right)f(v)\cos\theta\right]\frac{dg}{dv} = \Phi$$

Whence we easily obtain

$$\left.\begin{aligned} f(v)\frac{d^2g}{dv^2} + 2\left(1+\frac{d\theta}{dv}\right)f(v)\frac{dh}{dv} + 2f'(v)\frac{dg}{dv} &= \Psi\cos\theta - \Phi\sin\theta \\ f(v)\frac{d^2h}{dv^2} - 2\left(1+\frac{d\theta}{dv}\right)f(v)\frac{dg}{dv} + 2f'(v)\frac{dh}{dv} &= \Psi\sin\theta + \Phi\cos\theta \end{aligned}\right\} \quad . \quad . \quad (a)$$

If the second of these equations be multiplied by $i$, it follows that

$$\frac{d^2}{dv^2}(g+ih) + \left\{-2i\left(1+\frac{d\theta}{dv}\right) + 2\frac{f'(v)}{f(v)}\right\}\frac{d}{dv}(g+ih) = \frac{1}{f(v)}\left\{\Psi e^{i\theta} + i\Phi e^{i\theta}\right\}$$

or

$$\frac{d^2}{dv^2}(g-ih) + \left\{2\left(1+\frac{d\theta}{dv}\right) + 2\frac{f'(v)}{f(v)}\right\}\frac{d}{dv}(g-ih) = \frac{1}{f(v)}\left\{\Psi e^{-i\theta} - i\Phi e^{-i\theta}\right\}$$

The integration of the first of these equations leads to the result

$$\frac{d}{dv}(g+ih) = \frac{e^{2i(v+\theta)}}{[f(v)]^2}\int f(v)e^{-2iv-i\theta}[\Psi + i\Phi]dv,$$

and a similar result is obtained from the second. If, now, $\theta$ is a known function, $\frac{dg}{dv}$ and $\frac{dh}{dv}$ may be immediately computed, and afterwards $g$ and $h$. In the case, however, which now for a time demands our attention, this assumption is not suitable. We shall, on the contrary, assume that the function $\theta$ depends

directly on the quantities $g$ and $h$ to be determined, and that the relation between the three quantities is as follows—

$$\theta = \beta_2 \int \eta^2 dv \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\beta)$$

where $\beta_2$ denotes a small constant of the order of the disturbing masses, and where we have put $g^2 + h^2 = \eta^2$.

We suppose that $g$ and $h$ are small quantities of the order of excentricities; and, with respect to the functions $\Psi$ and $\Phi$, we retain the previous assumption, namely—

$$\Psi = \gamma \cos (\sigma v + \mathrm{B}), \; \Phi = \gamma \sin (\sigma v + B);$$

whence it follows that

$$\Psi \cos \theta - \Phi \sin \theta = \gamma \cos(\sigma v + \theta + B),$$
$$\Psi \sin \theta + \Phi \cos \theta = \gamma \sin (\sigma v + \theta + B).$$

Since, now, $g$ and $h$ must be determined as elementary functions of the form (A), we must assume that $\frac{d^2 g}{dv^2}$ and $\frac{d^2 h}{dv^2}$ belong to a higher order of magnitude than $\frac{dg}{dv}$ and $\frac{dh}{dv}$.

If we neglect in a first approximation the former as well as the products of $\frac{dg}{dv}$ and $\frac{dh}{dv}$ with $\frac{d\theta}{dv}$, we obtain

$$\left. \begin{aligned} g &= g_0 - \tfrac{1}{2}\gamma \int \sin (\sigma v + \theta + B)\, dv \\ h &= h_0 + \tfrac{1}{2}\gamma \int \cos (\sigma v + \theta + B)\, dv \end{aligned} \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (\gamma)$$

where $g_0$ and $h_0$ denote constants of integration, and the function $f$ is put equal to unity.

In many cases the expressions for the functions $g$ and $h$ may be freed from the integral sign by the application of the process of partial integration. We cannot, however, always obtain convergent developments by these means; and where we have to deal with terms which undergo so great an increase by integration that they may imperil the stability of the system, we have to strike out a new path.

We obtain a method more appropriate for our object if we form the sum of the squares of the equation ($\gamma$), multiply this sum by $\beta_2$, and, finally, differentiate the result. By referring to the equation ($\beta$) we then have

$$\begin{aligned} \frac{d^2\theta}{dv^2} = & -\beta_2 \gamma g_0 \sin (\sigma v + \theta + B) + \beta_2 \gamma h_0 \cos (\sigma v + \theta + B) \\ & + \tfrac{1}{2}\beta_2 \gamma^2 \sin (\sigma v + \theta + B) \int \sin (\sigma v + \theta + B)\, dv \\ & + \tfrac{1}{2}\beta_2 \gamma^2 \cos (\sigma v + \theta + B) \int \cos (\sigma v + \theta + B)\, dv \quad . \quad . \quad . \quad . \quad (\delta) \end{aligned}$$

If we regard the coefficient $\gamma$ as sufficiently small, we have the right to neglect in the first approximation the sum of the last two terms in the above equation. There then remains

$$\frac{d^2\theta}{dv^2} = -\beta_2\gamma g_0 \sin(\sigma v + \theta + B) + \beta_2\gamma h_0 \cos(\sigma\theta + v + B).$$

We here put

$$g_0 = e_0 \cos \varpi_0, \; h_0 = e_0 \sin \varpi_0,$$

and, further

$$2V = \sigma v + \theta + B - \varpi_0;$$

so that we obtain

$$\frac{d^2 V}{dv^2} = -\beta_2\gamma e_0 \sin V \cos V.$$

This equation may be integrated at once. The result is

$$\frac{dV}{dv} = \gamma_0 \sqrt{\left(1 - \frac{\beta_2\gamma e_0}{\gamma_0^2} \sin^2 V\right)},$$

where we denote the constant of integration by $\gamma_0^2$.

We write further

$$\frac{\beta_2\gamma e_0}{\gamma_0^2} = k^2,$$

and setting aside the constant which arises in the integration in hand, we finally obtain

$$V = am\,\gamma_0 v, \; mod.\, k.$$

From this there results therefore

$$\sigma v + \theta + B = 2\, am\, \gamma_0 v + \varpi_0.$$

The second approximation is to be computed from this, the process being easily carried out by means of Lamé's differential equation. It may be remarked that a term here makes its appearance which contains $v$ as a factor; it arises because we have neglected certain quantities in the original differential equations. In a rigorous treatment of these equations terms of this kind may always be avoided if they are not necessarily involved in the original differential equations.

The method explained above is also worthy of notice, because it is applicable when the quantities $\gamma \cos B$ and $\gamma \sin B$ are not constant, but are subelementary functions of the form (A).

In these cases the result is expressed by means of elliptic functions, with a variable modulus, which is in fact an elementary function of the form (A). The investigation of the differential equation which appears here I have treated in a memoir as yet unpublished. Dr. Harzer has, however, already made use of the most important part of it in his investigation of the absolute orbit of *Hecuba*.

In the application of the above method of investigation to the planetary theory $\gamma_0$ is a quantity of the order of the disturbing forces, and therefore of the same order as $\beta_2$; the constant

$\gamma$ is of the same order as $\beta_2 e_0$. Hence it follows that the modulus is of the same order as $e_0$—that is to say, of the order of the excentricities.

After this preface we resume the equation,

$$\frac{d^2(\rho)}{dv^2}+(1-\beta-X)(\rho)=M \quad . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

where we assume, as to the functions $X$ and $M$, that they give rise only to elementary or subelementary terms of the form (B) in $(\rho)$.

As in the following investigations we need not revert again to the function $\xi$, we may for brevity write $\rho$ instead of $(\rho)$. In consequence of the assumption that the result shall only contain terms of the form (B), we have also an equation of the form—

$$\begin{aligned}\rho=\kappa\ &\cos[(1-s)v-\Gamma]\\ &+\kappa_1\cos[(1-\sigma_1)v-B_1]+\kappa_2\cos[(1-\sigma_2)v-B_2]+\ .\ .\ .\ .\end{aligned}$$

where $\kappa$ and $\Gamma$ denote the two constants of integration. The remaining coefficients and angular constants depend partly on the elements of the orbits of the disturbing bodies, and, if they belong to terms of the higher class, partly also on $\kappa$ and $\Gamma$, as well as on the elements which determine the position of the orbit.

We now write

$$\begin{aligned}g=\eta\cos(\varpi-\Gamma)=\kappa&+\kappa_1\cos[(\sigma_1-s)v+B_1-\Gamma]\\ &+\kappa_2\cos[(\sigma_2-s)v+B_2-\Gamma]\\ &+\ .\ .\ .\ .\\ h=\eta\sin(\varpi-\Gamma)=\ \ &\kappa_1\sin[(\sigma_1-s)v+B_1-\Gamma]\\ &+\kappa_2\sin[(\sigma_2-s)v+B_2-\Gamma]\\ &+\ .\ .\ .\ .\end{aligned}$$

and thence obtain the following expression for $\rho$.

$$\rho=\eta\cos[(1-s)v-\varpi]$$

If now we put

$$\frac{d\rho}{dv}=-\eta\sin[(1-s)v-\varpi]-(\lambda)$$

we have

$$-(\lambda)=s\eta\sin[(1-s)v-\varpi]+\cos[(1-s)v-\Gamma]\frac{dg}{dv}+\sin[(1-s)v-\Gamma]\frac{dh}{dv}.$$

In accordance with previous assumption, the functions $X$ and $M$ depend on $\rho^2$; they may besides contain terms multiplied by $\eta^2$ and its powers, without affecting the intended form of the function $\rho$. We now conceive these functions separated into two in the following way:—

$$\begin{aligned}X&=\beta_2\eta^2+X_0+X_2+\beta_4\eta^2\cos[2(1-s)v-2\varpi]\\ M&=M_1+M_3\eta^2+(M),\end{aligned}$$

The functions $X_0$, $X_2$, $M_1$ and $M_3$ are as follows—

$$X_0 = \Sigma\beta_i^{(0)} \cos(\sigma_i v + B^{(0)})$$
$$X_2 = \Sigma\beta_i^{(2)} \cos[(2-\sigma_i)v - B_i^{(2)}]$$
$$M_1 = \Sigma\gamma_j^{(1)} \cos[(1-\sigma_j)v - B_j^{(1)}]$$
$$M_3 = \Sigma\gamma_j^{(3)} \cos[(1-\sigma_j)v - B_j^{(3)}]$$

where

$$\beta_i^{(0)}, \beta_i^{(2)}, \gamma_j^{(1)}, \gamma_j^{(3)}$$

denote constant coefficients of the order of the disturbing forces depending on the elements and on the indexes $i$ and $j$.

It is hardly necessary to remark that the $B$'s are angular constants and the $\sigma$'s small quantities of the order of the disturbing force. The function $M$ has obviously been added in order to annihilate non-elementary terms which may arise.

In the following operations the last term in $X$ would exercise a very detrimental influence, because, in a later integration, it would contain the variable $v$ as a factor. The term in question may, however, be at once easily eliminated. Let us write the above expression for $X$ as follows—

$$X = (\beta_2 + \tfrac{1}{2}\beta_4)\eta^2 + X_0 + X_2 + \beta_4\eta^2[\cos[2(1-s)v - 2\varpi] - \tfrac{1}{2}].$$

We remark that the last term may in general be omitted or joined to $M$, because on multiplication by $\rho = \eta\cos[(1-s)v - \varpi]$, it can only give rise to non-elementary terms. Terms of the same nature which make their appearance later may be set aside in a similar manner, and usually by only a small alteration of the constant.

We shall now endeavour to liberate the already simplified differential equation from the function $X_2$; this may be done by replacing $\rho$ by a new function, $\rho_1$, and $v$ by a new variable, $u$; $\rho_1$ and $u$ being defined by

$$\rho = \frac{\rho_1}{1+\psi},\ dv = \frac{du}{(1+\psi)^2}.$$

Let us further choose the, as yet, indeterminate function $\psi$ so as to satisfy the equation

$$\frac{d^2}{dv^2}(1+\psi) + (1+\psi)\{1 - \beta - X + X_2 + \Delta X\} = \frac{1-\beta-X}{(1+\psi)^3}. \quad . \quad . \quad (8)$$

By equation (7) we then obtain the following result:—

$$\frac{d^2\rho}{du^2} + \{1 - \beta - (\beta_2 + \tfrac{1}{2}\beta_4)\eta^2 - X_0 + \Delta X\}\rho_1 = \frac{M}{(1+\psi)^3} \quad . \quad . \quad . \quad (9)$$

We shall be able to dispose later of the function $\Delta X$, in such a way that $\psi$ may contain no terms of the form (A).

In passing on to the integration of equation (9), we write for brevity

$$Q = \beta + (\beta_2 + \tfrac{1}{2}\beta_4)\eta^2 + X_0 - \Delta X,$$

and put

$$\rho_1 = \frac{E_1}{\sqrt[4]{(1-Q_1)}}$$

in the equation

$$\frac{d^2\rho_1}{du^2} + (1-Q)\rho_1 = \frac{M}{(1+\psi)^3}.$$

Thus, we obtain

$$\frac{d^2E}{du^2} + \frac{1}{2}\frac{\frac{dQ_1}{du}}{1-Q_1}\frac{E}{du} + \left\{1 - Q + \frac{1}{4}\frac{\frac{d^2Q_1}{du^2}}{1-Q_1} + \frac{5}{16}\left(\frac{\frac{dQ_1}{du}}{1-Q_1}\right)^2\right\}E = \frac{\sqrt[4]{(1-Q_1)}}{(1+\psi)^3}M.$$

And if we define $Q_1$ by the equation

$$Q - \frac{1}{4}\frac{\frac{d^2Q_1}{du^2}}{1-Q_1} - \frac{5}{16}\left(\frac{\frac{dQ_1}{du}}{1-Q_1}\right)^2 = Q_1,$$

as may be very easily carried out by successive approximations, we have

$$\frac{d^2E}{du^2} + \frac{1}{2}\frac{\frac{dQ_1}{du}}{1-Q_1}\frac{dE}{du} + (1-Q_1)E = \frac{\sqrt[4]{(1-Q_1)}}{(1+\psi)^3}M \quad . \quad . \quad . \quad . \quad (10)$$

The integral of this equation is known. When $M=O$, whilst $c_1$ and $c_2$ are constants of integration, the solution is

$$E = c_1 \cos\left[\int \sqrt{(1-Q_1)}du\right] + c_2 \sin\left[\int \sqrt{(1-Q_1)}du\right]$$

The particular integrals of the equation (9), except as regards a constant factor, always involve the supposition that

$$y_1 = \frac{\cos\left[\int \sqrt{(1-Q_1)}du\right]}{\sqrt[4]{(1-Q_1)}}; \quad y_2 = \frac{\sin\left[\int \sqrt{(1-Q_1)}du\right]}{\sqrt[4]{(1-Q_1)}}.$$

One sees by the light of the preceding indications how the complete integral of this equation must be developed. The steps which are still necessary for the solution of the differential equation for the function

$$\theta = \beta_2\int \eta^2 dv$$

involve too many details to be here entered on.

If we look back at the expressions for the functions $g$ and $h$, we easily perceive that the constant part of $\eta^2$ (which will be denoted by $e_0^2$) is made up in the following manner—

$$e_0^2 = \kappa^2 + \kappa_1^2 + \kappa_2^2 + \quad . \quad . \quad . \quad .$$

By light of the preceding expressions we now easily perceive that the coefficient denoted by ς, which represents the ratio of the mean motion of the apses to that of the body, is given approximately by the formula

$$s = \frac{1}{2}\{\beta + (\beta_2 + \frac{1}{2}\beta_4)e_0^2\}.$$

If now the quantity $e_0$ is of the order of the excentricities—and that this is the case may be seen from the known motion of the apses in the principal planets—none of the coefficients $\kappa_1$, $\kappa_2$, &c., can become so large as to get out of their class. The number of the coefficients which belong to this class cannot be very great, because otherwise the quantity $e_0$ would increase beyond its indicated limit. These circumstances show, of course, that the series which we have obtained for $g$ and $h$, and also for the function $\rho$, converge; but the evidence is not complete, and we can merely say that this convergence is highly probable. The series, in fact, arise from series proceeding by successive powers, and in these series single individual terms may be increased by very small divisors of integration. Hence, if we set aside those individual terms, they will either converge or diverge, like series proceeding by successive powers. But there is another circumstance, which seems to put the convergence beyond all doubt, namely, that the convergence of the series for the differential coefficients of the function $\rho$, with reference to the variables $v$ or $u$, is as good as that of the development of the function itself.

The integration of equation (8) still remains, and for this we pursue the following method. We somewhat transform the equation, and write it as follows:—

$$\frac{d^2}{du^2}(1+\psi)+\left\{1-\beta-(\beta_2+\tfrac{1}{2}\beta_4)e_0^2\right\}\left\{1+\psi-\frac{1}{(1+\psi)^3}\right\}$$
$$=(1+\psi)\left\{(\beta_2+\tfrac{1}{2}\beta_4)(\eta^2-e_0^2)+X_0-\Delta X\right\}$$
$$-\frac{1}{(1+\psi)^3}\left\{(\beta_2+\tfrac{1}{2}\beta_4)\ (\eta^2-e_0^2)+X_0+X_2\right\}.$$

On the supposition that $\psi$ is a small quantity, we develop part of the last term of the right-hand side in ascending powers of $\psi$. Then putting

$$\beta+(\beta_2+\tfrac{1}{2}\beta_4)e_0^2=p,$$

we have

$$\frac{d^2}{du^2}(1+\psi)+(1-p)\left\{1+\psi-\frac{1}{(1+\psi)^3}\right\}=-\frac{X_2}{(1+\psi)^3}-\Delta X$$
$$+4\psi\left\{(\beta_2+\tfrac{1}{2}\beta_4)\ (\eta^2-e_0^2)+X_0\right\}$$
$$-\psi\Delta X\ \ldots.$$

Now this equation can be integrated by continued approximations. For this end I write,

$$\psi=\psi_0+\psi_1,$$

and define $\psi_0$ by the equation

$$\frac{d^2}{du^2}(1+\psi_0)+(1-p)\left\{1+\psi_0-\frac{1}{(1+\psi_0)^3}\right\}=-\frac{X_2}{(1+\psi_0)^3}-T. \quad . \quad (11)$$

where $T$ denotes function which is intended to transfer certain

terms to the equation next below, from which $\psi_1$ is determined. If we only write down the most important terms, this equation becomes

$$\frac{d^2\psi_1}{du^2}+(1-p)\{4+30\psi_0^2\}\psi_1=\mathrm{T}-\Delta X+4\psi\{(\beta_2+\tfrac{1}{4}\beta_4)(\eta^2-e_0^2)+X_0\}+\ldots \quad (12)$$

If the functions $X_2$ and $T$ vanish the integral of equation (11) may be given in a simple form; for we then have

$$1+\psi_0=\frac{\sqrt{[1-\vartheta\cos(2u\sqrt{(1-p)}-\Pi)]}}{\sqrt[4]{(1-\vartheta^2)}},$$

where $\vartheta$ and $\Pi$ denote the two constants of integration.

In the following developments I shall permit myself some abbreviations which, however, are quite unimportant in the final result. In the first place I simply equate the factor $\sqrt{(1-p)}$ to unity, whenever it is not seen to be multiplied by $u$.

The above value of $1+\psi_0$ must now be substituted in equation (11); the quantities $\vartheta$ and $\Pi$ must, however, no longer be regarded as constant, but must be so defined that the functions

$$\vartheta\cos\Pi=G;\quad \vartheta\sin\Pi=H,$$

may only contain elementary terms of the form ($A$). In order to fulfil this definition the function $T$ must be chosen in a corresponding manner.

In consequence of our supposition with regard to the functions $G$, $H$, and $\vartheta^2$ we shall neglect their second differentials, and then obtain from equation (11)—

$$\frac{3}{2}\frac{\sin w\dfrac{dG}{du}-\cos w\dfrac{dH}{du}}{\sqrt[4]{(1-\vartheta^2)}\sqrt{\left(1-\vartheta\cos(w-\Pi)\right)}}+\frac{3}{4}\cdot\frac{\left(\sin w\,.\,G-\cos w\,.\,H\right)\left(\cos w\dfrac{dG}{du}+\sin w\dfrac{dH}{du}\right)}{\sqrt[4]{(1-\vartheta^2)}\{1-\vartheta\cos(w-\Pi)\}^{\frac{3}{2}}}$$

$$+\frac{3}{8}\frac{\sin w\,.\,G-\cos w\,.\,H}{\{1-\vartheta^2\}^{\frac{5}{4}}\sqrt{\left(1-\vartheta\cos(w-\Pi)\right)}}\frac{d\vartheta^2}{du}$$

$$=-\frac{(1-\vartheta^2)}{\{1-\vartheta\cos(w-\Pi)\}^{\frac{3}{2}}}X_2-T,$$

where $w$ is written instead of $2u\sqrt{(1-p)}$.

The functions $G$ and $H$ must now be so defined as only to contain terms of the form (A). This condition is fulfilled if in the above equation the coefficients of $\cos w$ and $\sin w$ are made to vanish separately, and if at the same time all terms which do not satisfy the above condition are, by means of $T$, made to vanish.

If now we put

$$X_2=\Psi\cos w+\Phi\sin w,$$

where $\Psi$ and $\Phi$ only involve subelementary terms of the second

class of the form (A), we obtain, as applicable to the first approximation, the equations

$$\tfrac{3}{2}\frac{dG}{du}+\tfrac{3}{8}\frac{\frac{d\vartheta^2}{du}}{1-\vartheta^2}G=-(1-\vartheta^2)\Phi$$

$$\tfrac{3}{2}\frac{dH}{du}+\tfrac{3}{8}\frac{\frac{d\vartheta^2}{du}}{1-\vartheta^2}H=(1-\vartheta^2)\Psi$$

whence

$$G=-\tfrac{2}{3}\sqrt[4]{(1-\vartheta^2)}\int(1-\vartheta^2)^{\frac{3}{4}}\Phi du$$

$$H=\tfrac{2}{3}\sqrt[4]{(1-\vartheta^2)}\int(1-\vartheta^2)^{\frac{3}{4}}\Psi du,$$

also

$$\tfrac{3}{2}\frac{\left[\sin w\frac{dG}{du}-\cos w\frac{dH}{du}\right]\left[\cos w\,.\,G+\sin w\,.\,H\right]}{\{1-\vartheta\cos(w-\Pi)\}^{\frac{3}{2}}}$$

$$-\tfrac{3}{2}\frac{\left[\cos w\frac{dG}{du}+\sin w\frac{dH}{du}\right]\left[\sin w\,.\,G-\cos w\,.\,H\right]}{\{1-\vartheta\cos(w-\Pi)\}^{\frac{3}{2}}}$$

$$+\tfrac{3}{8}\frac{[\sin w\,.\,G-\cos w\,.\,H][\cos w\,.\,G+\sin w\,.\,H]}{(1-\vartheta^2)\{1-\vartheta\cos(w-\Pi)\}^{\frac{3}{2}}}$$

$$=\sqrt[4]{(1-\vartheta^2)}\,.\,T.$$

It may, however, be easily perceived that, in the development of this expression for $T$, terms arise of a high class—at least of the sixth—which may be retained in $G$ and $H$. There is no obstacle, however, to taking account of them in equation (12). It is indeed advantageous to take account, in the definition of $\psi_1$, of terms of higher classes, which may become very large in $G$ and $H$ by integration, and to incorporate them in that function. That such a term in $\psi_1$ cannot become of any arbitrary magnitude may be shown in the following manner.

For the sake of simplicity, we assume that in the value

$$\psi_0=\sqrt{\tfrac{8}{30}}\,.\,a\cos[(1-\sigma)w-A]$$

$a$ and A denote constants. According to the preceding explanation $a$ is an elementary coefficient of the second class, and consequently of the second order of excentricities, but is not multiplied by a factor of the order of the disturbing forces; $\sigma$, on the other hand, is, as before, of that order of magnitude.

If now this expression be substituted in equation (12) we obtain

$$\frac{d^2\psi_1}{dw^2}+\{1+a^2+a^2\cos[2(1-\sigma)w-2A]\}\psi_1=\tfrac{1}{4}T \quad . \quad . \quad . \quad . \quad (13)$$

For the integral of the equation found by putting $T$ equal to zero, an approximate value may be given, which is not only quite sufficient for our purpose, but even corresponds better than the complete value, because it is possible to judge more directly

of the magnitude of the constants which enter in the approximate than in the exact form. The approximate solution is

$$\psi_1 = c_1 \frac{\cos[(1-s)w] - \mu \cos[2(1-\sigma)w - 2A - (1-s)w]}{1 + \nu \cos[2(1-\sigma)w - 2A]}$$

$$+ c_2 \frac{\sin[(1-s)w] + \mu \sin[2(1-\sigma)w - 2A - (1-s)w]}{1 + \nu \cos[2(1-\sigma)w - 2A]}.$$

The constants of integration are here denoted by $c_1$ and $c_2$; $\mu$ is a coefficient which is very nearly equal to unity; and $\nu$, being $\frac{1}{8}a^2$, is a very small coefficient; and finally $s$ is given by the formula

$$s = \sigma \pm \sqrt{(\tfrac{3}{16}a^4 - a^2\sigma + \sigma^2)},$$

whence it is obvious that $s$ is a quantity of the fourth order with respect to the excentricities.

From the above expression, and from the magnitude of the quantity $s$, we must conclude that a subelementary term of the sixth class in $T$ will appear as a subelementary term of the second class in the function $\psi_1$.

It would carry us too far into details to extend this investigation to the more general case, where $a \cos A$ and $a \sin A$ are elementary functions of the form (A), and we must therefore pass this over.

It is often possible, by a very simple transformation, to reduce within the proper limits, terms which seem at first as though they would become very large in integration. It follows thence that we almost always carry out the integrations, after having partially developed the function to be integrated. Corresponding to this development there is also a certain development of the divisors of integration, which is not always convergent, even when the development of the function to be treated was, before integration, very highly convergent. These obstacles may be avoided by carrying over terms which occur in the wrong place in one equation, to another where the divisor of integration may be determined more correctly.

It would, however, lead to no useful result if, for example, we should propose to treat all the terms of $X_2$ in this function $\psi_1$, for the utility of equation (12) depends on the fact that the quantities $G$ and $H$, and also $\psi_0$, were found as elementary functions of the second class.

If now a term should exist in $M$ which would be very largely increased in $\rho_1$, the result must be regarded as inappropriate; but by carrying over this term to equation (12) we again obtain an appropriate result. The following steps are necessary for this end:—

Let the term in question be

$$\gamma \cos[(1-\sigma)v - B].$$

Since now

$$(1-\sigma)v - B = (2-\sigma-s)v - B - \Gamma - [(1-\sigma)v - \Gamma],$$

we have

$$\gamma \cos[(1-\sigma)v-B] = \gamma \cos 2W \cos V - \gamma \sin 2W \sin V,$$

where for brevity we write

$$V = [(1-s)v - \Gamma]$$
$$2W = (2-\sigma-s)v - B - \Gamma.$$

But

$$\rho = g \cos V + h \sin V$$
$$\frac{d\rho}{dv} = -g \sin V + h \cos V - (\lambda).$$

From which equations we easily deduce the following values :—

$$\eta^2 \cos V = g\rho + h\frac{d\rho}{dv} + h(\lambda)$$
$$\eta^2 \sin V = h\rho - g\frac{d\rho}{dv} - g(\lambda);$$

whence

$$\gamma \cos[(1-\sigma)v-B] = \frac{\gamma}{\eta^2}\{\cos 2W[g\rho + h\frac{d\rho}{dv} + h(\lambda)]$$
$$+ \sin 2W[h\rho - g\frac{d\rho}{dv} - g(\lambda)]\}.$$

From these results it is already obvious, without repeating the development, that the term in question will be carried over to the function $\Delta X$; for the term multiplied by $\frac{d\rho}{dv}$ may easily be eliminated. The term which is carried over will now appear in equation (12), and will be treated like the others. The result of this transposition depends actually both on the fact that the factor $\frac{1}{\eta^2}$ may be developed, and on the magnitude of the coefficient $\gamma$. The latter must belong at least to the third class, and must of course contain a factor of the order of the disturbing force.

We have above found expressions in which the variable $v$ is replaced by the new variable $u$. Since, then, the functions $X$ and $M$ were originally expressed in terms of the variable $v$, it is necessary to reduce the arguments which depend on $v$ to the variable $u$, and *vice versa*.

The equation

$$dv = \frac{du}{(1+\psi)^2}$$

serves as the basis for this operation.

We develop it as follows:

$$dv = \frac{du}{(1+\psi_0)^2} - \frac{2\psi_1 du}{(1+\psi_0)^4} + \frac{3\psi_1^2 du}{(1+\psi_0)^4} - \ldots$$

Since the even powers of $\psi_1$ contain constant terms, the non-periodic part of $v$ has the form

$$(1+g)u$$

where $g$ is a very small quantity, at least of the second order of the disturbing forces.

But the appearance of this constant would have been easily avoided if we had originally put

$$dv = \frac{(1+g)du}{(1+\psi)^2},$$

and had then determined $g$ in such a way that the non-periodic part of the coefficient of $du$ was equal to unity.

All of the terms, with the exception of the first by which $dv$ is represented above, are multiplied by a factor of the order of the disturbing forces; they can, after both integrations, at most become elementary. For since $\psi_0$ is not itself multiplied by a factor of the order of the disturbing forces, we might conjecture that in the integration of the term $\frac{du}{(1+\psi_0)^2}$ hyperelementary terms would make their appearance. This is, however, not the case, as we may easily convince ourselves by substitution of the value

$$1+\psi_0 = \frac{\sqrt{(1-\vartheta\cos(w-\Pi))}}{\sqrt{(1-\vartheta^2)}}.$$

If, in fact, we put $\vartheta = \frac{2a}{1+a^2}$, we have

$$\frac{du}{(1+\psi_0)^2} = \frac{(1-a^2)du}{1-2a\cos(w-\Pi)+a^2} = [1+2a\cos(w-\Pi)+2a^2\cos 2(w-\Pi)+\ldots]du.$$

An inspection of this expression suffices to convince us of the absence of hyperelementary terms.

In the preceding pages a method of computing the radius vector in the absolute orbit has been laid down, which does not, indeed, appear at present entirely free from objection in every point, but is, at any rate, characterised by the advantage that by it difficulties may be avoided which previous methods (for example, that of Leverrier) were not in a position to overcome.

I cannot close this explanation without making a remark which bears on the conception of the absolute orbit, in contrast with the conception of the so-called mean ellipse—assuming this latter conception to be in general possible. If we substitute for the elements in the formulæ of elliptic motion those functions which represent the secular variations by trigonometrical functions, we obtain the expressions for the motion in the absolute orbit. This orbit is, however, not an ellipse, nor in this formula of motion is Lagrange's condition,* $(\lambda)=0$, satisfied. An ellipse of which the elements are subjected only to secular inequalities, and which at the same time satisfies the above conditions, does not give what is required. The nomenclature 'mean ellipse' simply contains in itself a 'contradictio in adjecto.' The ellipse whose elements are subject to secular inequalities

* In the variations of the planetary element the corresponding equation is written somewhat differently.

may indeed be employed as a means of construction for indicating the absolute orbit; but it intersects the latter at an angle of the order of the product of the excentricity and of the disturbing force, and this angle only vanishes when the radius vector coincides with an apse.

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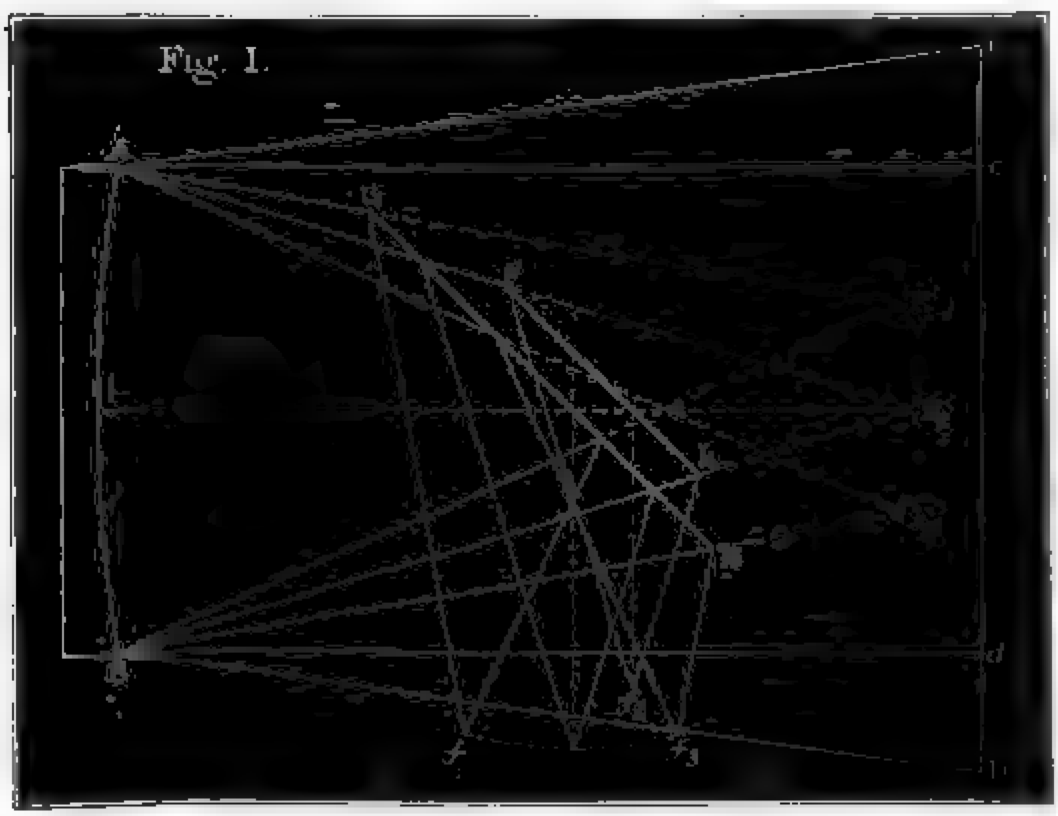
*Notes on Reflecting Telescopes, by* Lieut.-Gen. J. F. Tennant, R.E., F.R.S.

In the course of discussions as to making Reflecting Telescopes, I have been led to investigate some formulæ which have not, so far as I know, been published, and which seem likely to be of use.

It has been usual in designing a reflector for astronomical purposes to determine the size of the small mirror by a formula which only gives it large enough to receive and reflect all the rays which come from an object in the axis of the great speculum; and the tube is only so much larger than the speculum as is necessary to allow the space for the cell. When, however, it is desired to use the telescope for photographic purposes, and a field of some diameter is sought, this plan no longer suffices. I propose in the first place to consider the necessary dimensions of the small mirror and tube. M. Lœwy has given an approximate formula in a paper on "A New Form of Reflector" in the *Bulletin Astronomique.*




In Fig. I. let AB be a section of the parabolic speculum, with its geometrical focus at $F_2$, which will also be the focus of rays

parallel to the axis after reflection at the surface. So long as we only consider such rays, the mouth of the telescope need not be wider than *cd*, except by such amount as will suffice to make the rays quite clear of the edge, and a flat of the size *gh* in the position shown will reflect all the light to a focus at $f_2$ outside the tube. Denoting AB by $2r$ and the focal length by $a$, then it will only be necessary that $c$, the perpendicular distance of $f_2$ from the axis of the parabola, should be a little greater than half the diameter of the tube, and we shall have the following formula to determine the size of *gh* :—

$$\tan\phi = \frac{r}{a};\ m \text{ the minor axis of } gh = c\tan 2\phi \text{ and } l \text{ the major axis} = m\sqrt{2}.$$

If, however, the field subtends an angle $R_1AR_3 = L_1AL_1 = 2\alpha$, we shall have to modify the design as follows :—

1st. The mouth of the telescope must have an enlarged diameter CD.

2nd. The image formed by the great speculum alone will now be enough to fill the space $F_1F_3$, and we want to place it outside the tube in $f_1f_3$, we must place the small mirror (or flat) nearer the great one and enlarge its dimensions: it will now be represented by GH. Using the same symbols as before, we now have

$$CD > 2\,(r + Ac\tan\alpha) \text{ where } Ac \text{ is the length of the tube};$$

$$b = r\cot(\phi-\alpha);\ m = (b - a + c)\tan(2\phi - \alpha) \text{ and } l = m\sqrt{2}.$$

If $\alpha = 0$ $b = r$, and the formula is reduced to that before given.

In order to show how much precision is necessary for a field of some diameter, I will take the case of a telescope of 30 feet focus and 60 inches aperture, in which

$$\tan\phi = \frac{1}{12},$$

and

$$\phi = 4^\circ{\cdot}45'\,49''.$$

If only the image of a central object were required, we might assume $c = 36$ inches, and we should have

$$m = 6{\cdot}04 \text{ in.};\ l = 8{\cdot}55 \text{ in.}$$

If a field of 1° diameter be required, $c$ might be taken $= 37$ inches, and we should have

$$m = 11{\cdot}70 \text{ in.};\ l = 16{\cdot}55 \text{ in.}$$

If the field were 2° in diameter, we might retain 37 inches for $c$, but we should have

$$m = 17{\cdot}58 \text{ in.};\ l = 24{\cdot}86 \text{ in.}$$

For a field of 4° diameter we make $c = 39$ inches and thus should have

$$m = 29{\cdot}08 \text{ in., and } l = 42{\cdot}08 \text{ in.}$$

It is seen, that to obtain a field double the size of the Sun or Moon, it is necessary to nearly double the size of the small mirror, and to stop nearly four times the light which need be obstructed in order to define a star, and in all cases the centre of the flat will be out of the axis of the tube.

In the Cassegrain form of telescope, where the secondary speculum is placed between the great speculum and its focus, and an image is formed behind the great speculum, $c$ of our formula would represent the distance from the principal focus to the face of the secondary mirror measured along the axis of the tube, and our formulæ would be

$$\tan\phi = \frac{r}{a},$$

and

$$b = r\cot(\phi - \alpha) \text{ as before;}$$

and then

$$d \text{ the diameter of the secondary mirror} = 2(b - a + c)\tan(\phi - \alpha).$$

The value to be assigned to $c$ will depend upon the desired size of the image behind the speculum. If that is to be $m$ times larger than what is due to the great speculum alone, and $\delta$ be the distance which this image is behind the face of the speculum, then we should have

$$c = \frac{a + \delta}{1 + m}.$$

Applying this to the case of a great speculum of the same dimensions as before, we shall find that when $m = 1$ and the image is 12 inches behind the reflecting surface, $c = 186$ inches; if $m = 2$, then $c = 124$; if $m = 5$, then $c = 62$.

| | | |
|---|---|---|
| for $m = 1$. | The image of a point requires | $d = 31{\cdot}00$ |
| | a field of 1° diameter ,, | $d = 34{\cdot}00$ |
| | ,, 2° ,, ,, | $d = 37{\cdot}11$ |
| | ,, 4° ,, ,, | $d = 44{\cdot}20$. |
| for $m = 2$. | The image of a point requires | $d = 20{\cdot}67$ |
| | a field of 1° diameter ,, | $d = 24{\cdot}76$ |
| | ,, 2° ,, ,, | $d = 28{\cdot}95$ |
| | ,, 4° ,, ,, | $d = 37{\cdot}21$. |
| for $m = 5$. | The image of a point requires | $d = 10{\cdot}00$ |
| | a field of 1° diameter ,, | $d = 15{\cdot}27$ |
| | ,, 2° ,, ,, | $d = 19{\cdot}22$ |
| | ,, 4° ,, ,, | $d = 30{\cdot}07$. |

Clearly, then, the size of the mirror obstructing the light would be very large, unless the focal image of the great speculum were considerably magnified, and the field very restricted; so that this form of telescope, however well adapted for the examination of small objects, is not suitable for photography.

The Gregorian form of telescope requires larger secondary mirrors than the Cassegrain for small objects, and in all cases a longer tube, which is a serious evil. Probably it will not be selected for use in any case, unless it should be found that the concave form of the small mirror is easier to produce than the convex one required for the Cassegrain. The appropriate formulæ in this case will be

$$c = \frac{a}{m-1} \cdot \quad b = r \cot(\phi + a),$$

$$d = (a + c - b) \tan(\phi + a).$$

On the whole it would seem that for photographic purposes a large telescope would probably be best designed for a front view, with the sensitive surface facing the speculum, and no second reflection. In such a telescope as I have spoken of before, a field of 4° would be about 25 inches in diameter, whereas the small mirror even for a Newtonian would have 29 inches for its minor axis, and the difference (if a round plate were used) would be ample for the holder and exposing arrangements. If, for convenience, a plate of the usual form were used, then the Newtonian form of telescope would have a slight advantage if the field were very large; but not with a small field. Thus a field of 1° diameter would be 6·5 inches across, and the diagonal of a square plate which would include this field would be 9·2 inches, which is less than 11·7 inches required for the minor axis of the small mirror.

When the flat or small mirror is insufficiently large it will produce a field whose brightness diminishes rapidly in passing away from the proper limit; and, moreover, when either the small speculum or the mouth of the tube is too small, the portion of the great speculum used to produce the image of an object near the margin of the field will not be circular, and we may expect some falling off in definition.

I next proceed to examine the image formed by a parabolic speculum. Let Fig. II. be a section through the axis AX of the parabola, whose revolution round it generates the surface of the speculum, PA being the curve, of which A is the vertex and S the focus. Take the axis of the parabola for the axis of X, and A as the origin of rectangular co-ordinates.

Suppose three rays, $L_1P_1$, $LP_1$, and $L_2P_1$, to be incident on a point P, whose co-ordinates are $x'$ and $y'$. Then the reflected ray corresponding to $LP_1$ will pass through S. Let $P_1Q$ and $P_1q$ be the directions of the other two rays respectively. Call $a$ the angle between $P_1L$ and each of the other incident rays; then

it will also be the angle between $PS_1$ and either $P_1Q$ or $P_1q$. Make $\tan \alpha = c$.

Let $S_1$ be the focus for rays incident on $P_1$ and in the direction $L_1P_1$, and let its co-ordinates be $x_1, y_1$. Write $v$ for $\frac{y'}{a}$, then $x' = \frac{av^2}{4}$. Also write $h$ and $k$ for $\frac{x}{a}, \frac{y}{a}$ respectively.

Then

$$\tan P_1SA = \frac{y'}{a - x'},$$

and the angle

$$P_1QA = P_1SA - \alpha,$$

therefore

$$\tan P_1QA = \frac{\frac{y'}{a - x'} - c}{1 + \frac{cy'}{a - x'}} = \frac{y' + cx' - ca}{a + cy' - x'},$$

and the equation to $P_1S_1$ will be

$$y - y' = \frac{ca - cx' - y'}{a - x' + cy'}(x - x'),$$

or

$$a(k - v) = \frac{ca - \frac{cav^2}{4} - av}{a - \frac{av^2}{4} + cav}\left(ah - \frac{av^2}{4}\right)$$

or

$$4(k - v) = \frac{4c - cv^2 - 4v}{4 - v^2 + 4cv}(4h - v^2)$$

Now differentiating with respect to $v$, $k$ will disappear, and the value of $h$ deduced from the result will be $h_1$, the value of

$h$ at $S_1$. Performing this operation and changing the signs we get

$$4 = 2v\frac{4c-cv^2-4v}{4-v^2+4cv} + (4h_1-v^2)\frac{(4+2cv)(4-v^2+4cv)+(4c-2v)(4c-cv^2-4v)}{(4-v^2+4cv)^2}$$

whence

$$4h_1 = v^2 + \frac{32+48cv+16cv^2+8cv^3+2(2c^2-1)v^4-cv^5}{2(1+c^2)(4+v^2)}$$

and

$$h_1 = \frac{8+12cv+6c^2v^2-cv^3}{8(1+c^2)},$$

or

$$x_1 = \frac{a}{8}\cos^2\alpha\,\{8+(12-v^2)\,v\tan\alpha+6v^2\tan^2\alpha\}$$

Evidently, if $x_2$ be the co-ordinate for a similar ray incident on $P_2$ opposite $P_1$, we shall have

$$x_2 = \frac{a}{8}\cos^2\alpha\{8-(12-v^2)\,v\tan\alpha+6v^2\tan^2\alpha\}$$

by changing the sign of $v$.

Substituting the value of $h_1$ in the value found for $4k$ we shall get $k_1$, the value of $k$ at $S_1$,

$$k_1 = \frac{c}{8(1+c^2)}\{8+12\,cv-6v^2-cv^3\},$$

or

$$y_1 = \frac{a}{8}\sin\alpha\cos\alpha\,\{8+(12-v^2)\,v\tan\alpha-6v^2\}$$

and we shall have

$$y_2 = \frac{a}{8}\sin\alpha\cos\alpha\,\{8-(12+v^2)\,v\tan\alpha-6v^2\}$$

also

$$x_1-x_2 = \frac{av}{4}\cos\alpha\sin\alpha\,(12-v^2),$$

and

$$y_1-y_2 = \frac{av}{4}\sin^2\alpha\,(12-v^2).$$

When an oblique ray is incident at the centre of the speculum, we shall have

$$v = 0$$

and

$$x_1 = x_2 = a\cos^2\alpha,\quad y_1 = y_2 = a\cos\alpha\sin\alpha.$$

Hence the locus of the foci of such rays will be a spherical surface touching the paraboloid at its vertex, and passing

through the focus; its radius will be $\frac{a}{2}$,* and there will be no aberration.

In the case of a telescope of the dimensions I have spoken of we shall have

| | | $v=+\frac{1}{12}$ in. | $v=0$ in. | $v=-\frac{1}{12}$ in. |
|---|---|---|---|---|
| Field 4° diameter | $x+$ | 361·1325 | 359·5615 | 357·9953 |
| | $y+$ | 12·5455 | 12·5562 | 12·4360 |
| Field 2° diameter | $x+$ | 360·3735 | 359·9981 | 359·5885 |
| | $y-$ | 3·1449 | 3·1414 | 3·1380 |

The above applies to rays oblique to the axis of the telescope, and incident on small surfaces at any part of the speculum in the plane containing the axis and the incident ray. I now proceed to consider the case of a ray falling at a point out of this plane, and at a distance $r$ from the axis. Calling the plane I have used the principal plane, let the line $r$ make an angle with it $=\phi$.

Let $x$, $y$, $z$ be co-ordinates whose origin is the vertex, and whose directions are: of $x$ in the axis, of $y$ perpendicular to it in the principal plane, and of $z$ perpendicular both to the axis and principal plane; and let $x_0$, $y_0$, $z_0$ be the corresponding co-ordinates when the plane containing $r$ and the axis is substituted for the principal plane. In this case the projection (on the plane $XY_0$) of the ray incident at the vertex will be inclined to the axis of X at an angle whose tangent is $c=\tan\alpha\cos\phi$.

Hence $\left(\text{making } v=\frac{r}{a}\right)$ the equations of the reflected ray will be; in the plane $X_0$

$$y_0-av=\frac{4c-4v-cv^2}{4+4cv-v^2}\left(x-\frac{av^2}{4}\right)$$

or

$$y_0=\frac{c(4-v^2)-4v}{4-v^2+4cv}x+\frac{16+12cv+cv^3}{4-v^2+4cv}\cdot\frac{av}{4}$$

and in the plane $XZ_0$

$$z_0=\left(\frac{av^2}{4}-x\right)\tan\alpha\sin\phi.$$

* I am indebted to the Astronomer Royal for a very elegant geometrical demonstration of this property.

Through A draw $A\sigma$ parallel to $AL_2$, and cutting $P_1Q$ in $\sigma$. Then $A\sigma$ will be the reflected direction of the ray incident at A and parallel to $L_1P_1$, and the two angles $SP_1\sigma$ and $SA\sigma$ will each $=\alpha$. Hence a circle can be described through A, $P_1$, $\sigma$, and S. If P move towards A, $\sigma$ will gradually move towards $S_1$, and when P is at A will coincide with it, and in this limiting position the circle will touch the vertex of the parabola at A, and pass through $S_1$ and S.

Also since

$$y = y_0 \cos\phi - z_0 \sin\phi$$

and

$$z = y_0 \sin\phi + z_0 \cos\phi$$

we have

$$y = x\left\{\frac{c(4-v^2)-4v}{4-v^2+4cv}\cos\phi + \tan\alpha\sin^2\phi\right\} + \frac{av}{4}\left\{\frac{16+12cv+cv^3}{4-v^2+4cv}.\cos\phi - v\tan\alpha\sin^2\phi\right\}$$

$$= \left(x - \frac{av^2}{4}\right)\tan\alpha + v\cos\phi\left\{a + \left(av^2 - 4x\right)\frac{1+\tan^2\alpha\cos^2\phi}{4-v^2+4v\tan\alpha\cos\phi}\right\}$$

and

$$z = x\left\{\frac{c(4-v^2)-4v}{4-v^2+4cv}\sin\phi - \tan\alpha\sin\phi\cos\phi\right\}$$

$$+\frac{av}{4}\left\{\frac{16+12cv+cv^3}{4-v^2+3cv}\sin\phi + v\tan\alpha\sin\phi\cos\phi\right\}$$

$$= av\sin\phi.\frac{(2+v\tan\alpha\cos\phi)^2}{4-v^2+4v\tan\alpha\cos\phi} - 4x\sin\phi.\frac{v(1+\tan^2\alpha\cos^2\phi)}{4-v^2+4v\tan\alpha\cos\phi}$$

$$= av\sin\phi + v\sin\phi(av^2-4x)\frac{1+\tan^2\alpha\cos^2\phi}{4-v^2+4v\tan\alpha\cos\phi};$$

and if we make

$$R = av - v(4x - av^2)\frac{1+\tan^2\alpha\cos^2\phi}{4-v^2+4v\tan\alpha\cos\phi},$$

we shall have

$$y = \left(x - \frac{av^2}{4}\right)\tan\alpha + R\cos\phi$$

$$z = R\sin\phi.$$

If $v = 0$ we have $y = n\tan\alpha$, $z = 0$. This is the case of incidence at the vertex, and the reflected ray passes as it should through the focus in this case as before found.

If $\sin\phi = 0$ then $z$ will always be 0. In this case, of course, the incident and reflected rays lie in the principal plane.

We see that—

1st. If we write $-\phi$ for $\phi$, $z$ will only change in sign, not in magnitude, while $y$ will be unchanged. Therefore for any value of $y$ there will be two equal values of $z$, with opposite signs, and the trace of the principal plane will divide the curve into two similar parts.

2nd. If $\sin\phi = 0$, then $z = 0$; but from value of R, we see that $r$ and R will $= 0$ if

$$x = \frac{a}{4}.\frac{(2+v\tan\alpha\cos\phi)^2}{1+\tan^2\alpha\cos^2\phi},$$

and we find that this will also be the case if

$$\cos\phi = \frac{2av \pm \sqrt{x(4a - 4x + av^2)}}{(4x - av^2)\tan\alpha}$$

This value of $\cos\phi$ becomes impossible if

$$x > a\left(1 + \frac{v^2}{4}\right).$$

When $x$ exceeds this value, R cannot be $= 0$, but $z$ will $= 0$ when $\sin\phi = 0$. Otherwise $\cos\phi$ may have two different values for which R and $z$ vanish: these correspond to a point which is either double or quadruple.

It is needless to spend labour on seeking the place where the rays are most concentrated. The question of focus of the whole speculum in such a case seems to me likely to be affected a good deal by the causes which would make the image of a point of light, even in the case of a perfect reunion of the rays, to be a disc surrounded by rings.

I purpose adding some numerical results. As a circle, whose diameter is $1 + \sqrt{2}$ of that of the speculum, will separate the surface into two zones, receiving equal amounts of light, I will only consider that ring as a mean case, and I shall assume $x = a\cos^2\alpha$. In other respects I have used the dimensions I have taken before for the data of the telescope and calculated co-ordinates.

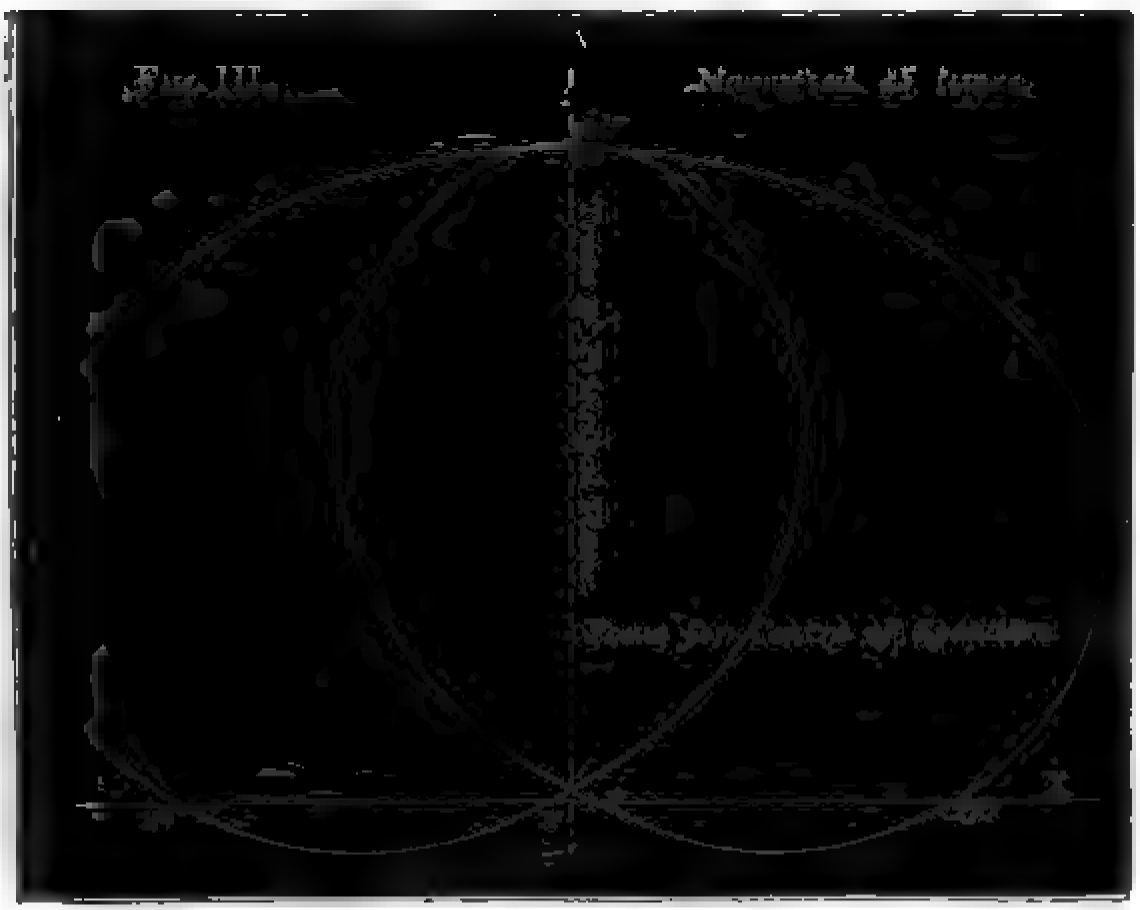
I shall assume $\alpha$ to be equal to $2°$, or the field to be $4°$ in diameter, and from the values of $y$ I shall omit $\left(x - \frac{av^2}{4}\right)\tan\alpha$; the whole of the co-ordinates will be expressed in thousandths of an inch.

When $R = 0$, besides the two universal values of $\cos\phi \pm 1$, we shall only have one value of $\cos\phi$ possible, namely, that corresponding to $\phi = 117° \; 42' \; 49''\cdot73$. And I may remark that only one such value of $\cos\phi$ will be possible when we are dealing with practical cases; because near, and at the focus, $x$ will not differ much from $a$; therefore the quantity under the radical sign in the numerator will not vary much from $av$, and the two values of the numerator will be, one very small, and the other not very far from $2\,av$; the denominator, on the other hand, will approach $4a\tan\alpha$ $\left(\frac{v^2}{4}\text{ being small compared with } 1\right)$, but $\tan\alpha$ will, for the outer part of the speculum, which alone is available, be much smaller than $v$; and, of the two values of $\phi$, one will be small as possible, the other greater than 1.

| | Co-ordinates. | | | Co-ordinates. | |
|---|---|---|---|---|---|
| $\phi$ | $y-\left(x-\frac{ar^2}{4}\right)\tan^2\alpha$ | $z$ | $\phi$ | $y-\left(x-\frac{ar^2}{4}\right)\tan^2\alpha$ | $z$ |
| 0° | +43·62 | 0·00 | 90° | − 0·00 | +25·85 |
| 10 | +42·99 | + 7·58 | 100 | − 3·04 | +17·45 |
| 20 | +41·35 | +15·04 | 110 | − 2·70 | + 7·42 |
| 30 | +38·31 | +21·78 | 120 | + 1·22 | − 1·13 |
| 40 | +33·78 | +28·86 | 130 | + 8·31 | − 9·90 |
| 50 | +27·76 | +33·09 | 140 | +17·47 | −14·66 |
| 60 | +20·60 | +35·68 | 150 | +27·20 | −15·71 |
| 70 | +12·91 | +35·48 | 160 | +35·79 | −12·29 |
| 80 | + 5·67 | +32·29 | 170 | +41·74 | − 7·31 |
| 90 | + 0·00 | +25·85 | 180 | +43·75 | − 0·00 |

The co-ordinates for the values of $\phi$ from 180° to 360° will be those for $2\pi-\phi$ with the sign of $z$ changed.

Of the portion of the value of $y$ which I have omitted,




$x\tan\alpha$ is the value of $y$ for centrally incident rays, and the remainder $\frac{ar^2}{4}\tan\alpha$, equal to 10·96 thousandths of an inch, is the amount by which the focus of centrally incident rays is farther from the axis than the point from which the values in the table are reckoned: its cause will be evident if we observe

that $\frac{av^2}{4}$ is the portion of the axis of the parabola intercepted between the vertex, and the plane by whose intersection with the parabolic surface the reflecting ring is defined. I have plotted the curve in Fig. III. much enlarged, and shown on it the position of the focus of a centrally incident ray. The width perpendicular to the trace of the principal plane is 39·5 seconds of span.

When $x = a$ we shall have the case of the plane of the image being defined by its passing through the principal focus and being perpendicular to the axis. In this case

$$R = av\left\{1 - \left(1 - \frac{v^2}{4}\right)\frac{1 + \tan^2\alpha\cos^2\phi}{1 - \frac{v^2}{4} + v\tan\alpha\cos\phi}\right\}$$

$$= av\tan\alpha\cos\phi\,\frac{\frac{v}{1 - \frac{v^2}{4}} - \tan\alpha\cos\phi}{1 + \frac{v}{1 - \frac{v^2}{4}}\tan\alpha\cos\phi}.$$

If we assume

$$\tan A = \frac{v}{1 - \frac{v^2}{4}}$$

and

$$\tan B = \tan\alpha\cos\phi,$$

we shall have

$$y = a\left(1 - \frac{v^2}{4}\right)\tan\alpha + av\cos\phi\tan B\tan(A - B)$$

$$z = av\sin\phi\tan B\tan(A - B)$$

Moving the origin to the point*

$$a\left(1 - \frac{v^2}{4}\right)\tan\alpha,\ 0$$

and using R and $\phi$ as the polar co-ordinates of the curve, we shall have

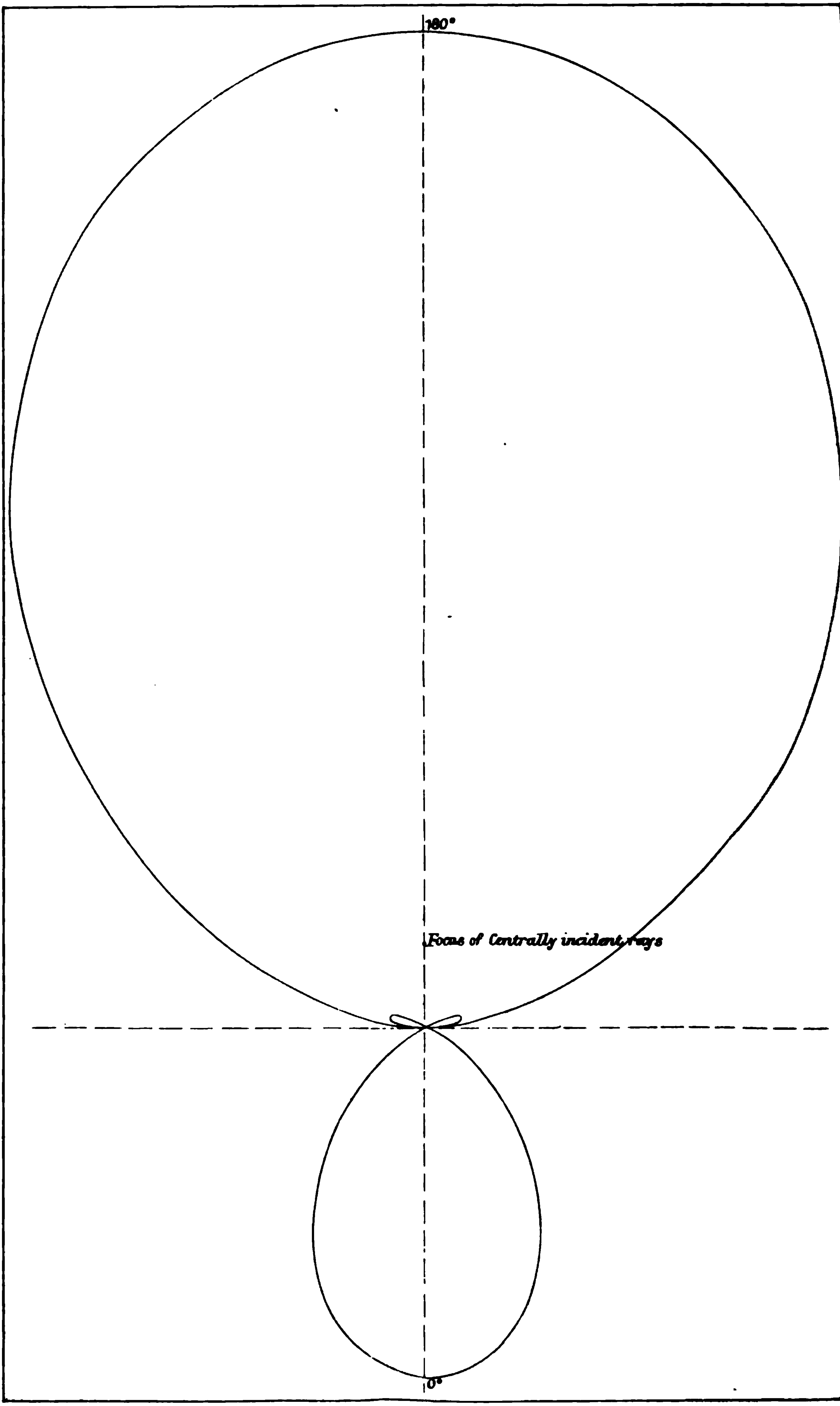
$$R = av\tan B\tan(A - B)$$

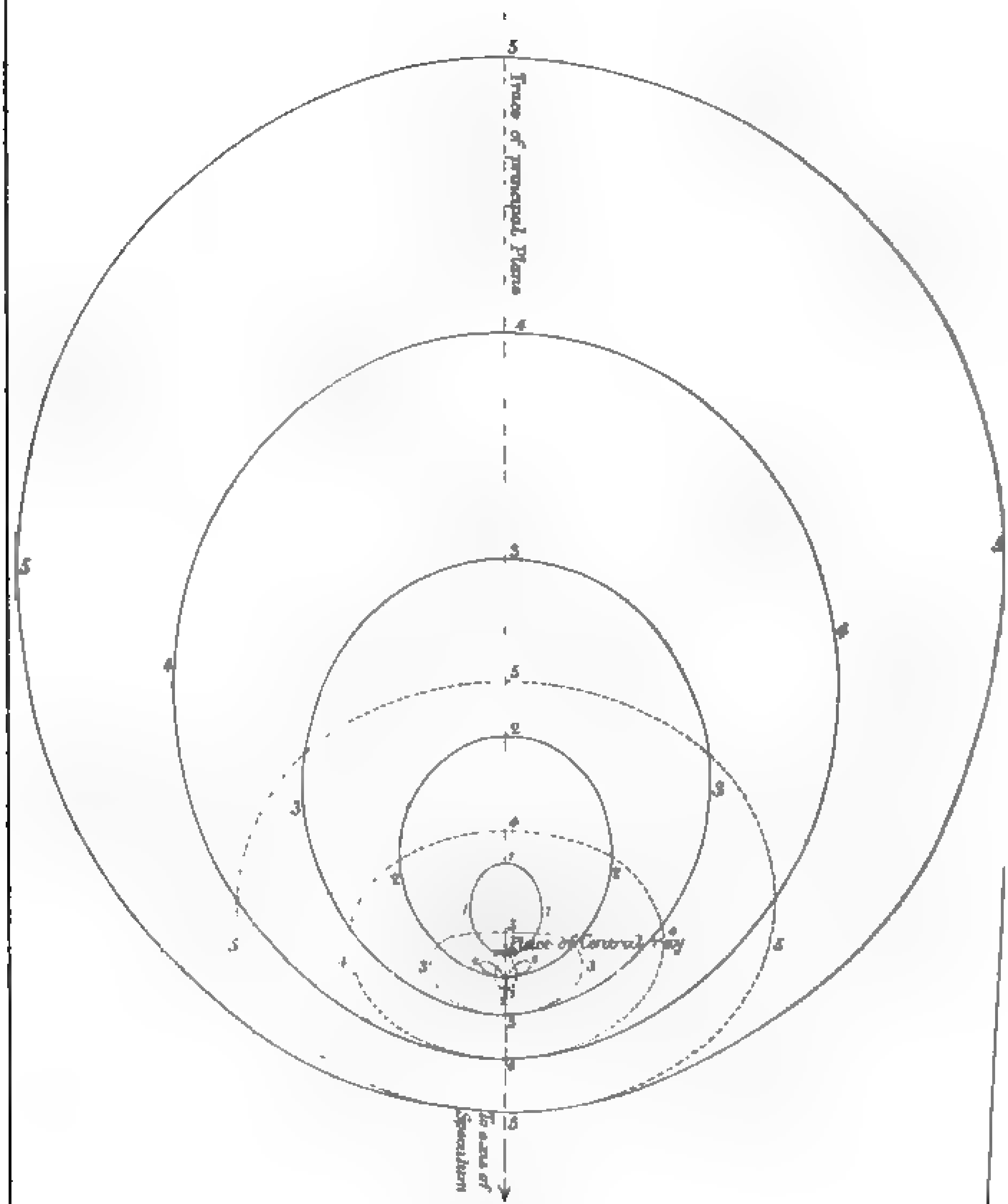
where A and B have the values above given, in which A depends only on $v$ and B on $\alpha$ and $\phi$.

In this case the values of $\cos\phi$ for $z = 0$ will be

$$+1,\ -1.\ 0.\ \text{and}\ \frac{v}{\left(1 - \frac{v^2}{4}\right)\tan\alpha}$$

* If the plane of the reflecting ring were itself a reflecting plane, then the ray incident at its intersection with the axis would pass through this point.


180°
Focus of Centrally incident rays
0°




| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Length of Curve* | 1, | *solid line,* | 5″.00; | *dotted line,* | 2″.69; | *whole,* | 8″.10 |
| ,, | ,, | 2, | ,, | 15″.86; | ,, | 2″.28; | ,, | 16″.54 |
| ,, | ,, | 3, | ,, | 29″.62; | ,, | 5″.25; | ,, | 29″.62 |
| ,, | ,, | 4, | ,, | 47″.28; | ,, | 14″.73; | ,, | 47″.28 |
| ,, | ,, | 5, | ,, | 68″.86; | ,, | 28″.08; | ,, | 68″.86 |

for both the last values $y$ is reduced to the term

$$a\left(1-\frac{v^2}{4}\right)\tan\alpha \text{ and } R=0,$$

hence the corresponding points will be quadruple if

$$\left(1-\frac{v^2}{4}\right)\tan\alpha$$

be $< 1$, and double it if it be $> 1$.

This position would be that of most interest for photography, I have therefore computed the values of R for five equidistant rings of the speculum I have so often spoken of, and plotted them on a large scale in the annexed Plate 2* in which the dotted portion of each curve is due to the portion of the ring where $\cos\phi$ is positive, and the continuous portion to the remainder: $\alpha$ is assumed as $2°$.

The place of the ray reflected at the vertex of the speculum is marked. It will be seen that as the ring increases in size the multiple point recedes towards the axis of the speculum; at first, while $v$ is small, the curve is four-looped with two small loops; as $v$ increases the loop towards the axis becomes smaller, while the others, and particularly the two side loops, increase in size. When

$$\tan\alpha=\frac{v}{1-\frac{v^2}{4}}$$

the loop towards the axis vanishes, the multiple point is momentarily triple, and two of the branches form a cusp, the trace of the principal plane being a tangent to both branches. As $v$ continues to increase, this cusp becomes a salient point, recedes from the axis, and gradually becomes effaced, the loops swell, and the curve gradually becomes one with only two rounded loops, with a common point in the axis.

We can form some idea now of the general distribution of the illumination, by picturing to ourselves a greatly increased number of these images from rings—the total image will be that of course arising from considering $v$ to vary continuously from 0 to its maximum value. It would seem, that just behind the place of the ray reflected from the vertex, there will be a maximum of illumination in a bright ray extending from the place of the central ray towards the axis; from this the light will decrease. The lines of equal brightness will have a tendency to an oval form, and beyond this the light will spread out in the well-known fan shape.

If we consider what would be the result of photographing an object of this sort, I think it will be seen to be as follows. With comparatively short exposures the image will be elongated in

* Plate 1 shows the innermost curve on a larger scale.

the direction of the trace of the principal plane; as the exposure is increased the image will become more round, and probably only a very long exposure indeed would exhibit the outer parts of the fan. After the exposure has been long enough to efface the nucleus by rendering less illuminated portions of the image opaque, the centre of the image will seem to move outwards from the axis with increasing exposure. No doubt such an effect would be very small, but it seems to me it will exist.

On the whole, I am disposed to think that the parabolic speculum will have great advantages for a small field in photographing planets, nebulæ, &c., but that if a large area be required, there will be rapidly increasing astigmatism,* soon becoming unbearable. For eye views, when the field is small, whether used in the Newtonian, the Herschelian, or even the Brachy form, it will work satisfactorily, especially if the focal length be long in proportion to the aperture. Whether opticians may be able to produce a surface in which by sacrificing some of the perfection of the central image a bearable average result can be obtained over a large field, I cannot say, but I doubt it. It is true that the image for photography does not need to be so perfect as for vision of a small object under a high power, but the image of a star should be round, and its position should not vary with the aperture. The devices by which opticians have sought to gain large fields in achromatic lenses for photography do not seem applicable in any way to specula, and I do not see any others.

Lastly. To find the focus of a ring of a parabolic mirror, when the centre of curvature at the vertex is the origin of light, and also, under the same circumstances, to find the focus of a small patch of the speculum.


In Fig. IV. let P be a point in the ring and A the vertex of the parabola, by whose revolution round its axis AX the specu-

* It must be remembered that in order to photograph we mus block out the centre of the field which gives a nucleus to the image. When the field is large we may from this cause even have a dark-centred image.

lum is defined. Let S be the focus of the parabola, C the centre of curvature at the vertex, then AC = $2a$. Also draw PM perpendicular to the axis AX, and PN the normal at P, then MN = $2a$. And if PF$f$ be the reflected ray (PC being incident) we shall have the angle CPN = angle NPF. I shall assume A as the origin of rectangular co-ordinates, and AX as the axis of X. PM = $y'$, AM = $x'$.

$$\frac{y'}{a} = v$$

as before, and consequently

$$x' = \frac{av^2}{4}.$$

The angle

$$\text{CPN} = \text{PCM} - \text{PNM}$$

and

$$\tan \text{PCM} = \frac{y'}{2a - x'} = \frac{4v}{8 - v^2}$$

also

$$\tan \text{PNM} = \frac{y'}{2a} = \frac{v}{2}.$$

Hence

$$\tan \text{CPN} = \frac{\dfrac{4v}{8 - v^2} - \dfrac{v}{2}}{1 + \dfrac{2v^2}{8 - v^2}} = \frac{v^3}{16 + 2v^2}.$$

Whence

$$\tan \text{AFP} = (\text{MNP} - \text{CPN}) = \frac{\dfrac{v}{2} - \dfrac{v^3}{16 + 2v^2}}{1 + \dfrac{v^4}{32 + 4v^2}} = \frac{16v}{32 + 4v^2 + v^4}.$$

The equation to PF$f$ will therefore be

$$y - av = \frac{16v}{32 + 4v^2 + v^4}\left(\frac{av^2}{4} - x\right)$$

or

$$y = a \, . \, \frac{32v + 8v^3 + v^5}{32 + 4v^2 + v^4} - x \, . \, \frac{16v}{32 + 4v^3 v^4}.$$

When

$$y = 0 \quad x = a \, . \, \frac{32 + 18v^2 + v^4}{16} = 2a + \frac{av^2}{2} + \frac{av^4}{16}$$

which value corresponds to F, and this will manifestly be the place of the bright image from the ring whose diameter is $av$ or MP. Also

$$\text{CF} = \frac{av^2}{2}\left(1 + \frac{v^2}{8}\right)$$

Reverting to the equation

$$y=a\,.\,\frac{32v+8v^3+v^5}{32+4v^2+v^4}-x\,.\,\frac{16v}{32+4v^2+v^4}$$

and differentiating with effect to $v$ we have

$$\frac{dy}{dv}=a\,.\,\frac{1024+640v^2+96v^4+4v^6+v^8}{(32+4v^2+v^4)^2}-16x\,.\,\frac{32-4v^2-3v^4}{(32+4v^2+v^4)^2}$$

and since when

$$\frac{dy}{dv}=0,\quad x=\text{A}f(f\text{ being the focus of the ray})$$

we have

$$\text{A}p=\frac{a}{16}=2a+\frac{a}{16}\left\{24v^2+9v^4+\frac{7}{2}v^6+\&\text{c.}\right\}\frac{1024+640v^2+96v^4+4v^6+v^8}{32-4v^2-3v^4}$$

and

$$\text{C}p=a\left\{\frac{3}{2}v^2+\frac{9}{16}v^4+\frac{7}{32}v^6+\&\text{c.}\right\}$$

Also substituting the value of $Ap$ for $x$ in the equation for $y$ we have

$$pf=-av^3.\frac{512+192v^2+32v^4+4v^6}{1024-80v^4+16v^6-3v^8}=-av^3\left\{\frac{1}{2}+\frac{3}{16}v^2+\frac{9}{128}v^4+\&\text{c.}\right\}$$

the values of A$p$ and $pf$ being true to $v^7$, which is more than enough.

These values of C$f$, A$p$ and $pf$ will serve in verifying the form of a speculum during the polishing process.

*Data for Light Curves.*

$a=360{\cdot}000$ inch; $\alpha=2^\circ:00'$.

The units for the values of R is 0·001 inch.

No. 1.—$v=\frac{1}{60}$.

| $\phi$ | R | $\phi$ | R | $\phi$ | R | $\phi$ | R | $a\frac{v^2}{4}\tan\alpha$ |
|---|---|---|---|---|---|---|---|---|
| 0° | − 3·82 | 50° | − 0·78 | 100° | − 0·83 | 150° | − 8·52 | |
| 10 | − 3·66 | 60 | − 0·11 | 110 | − 2·06 | 160 | − 9·85 | |
| 20 | − 3·25 | 70 | + 0·34 | 120 | − 3·50 | 170 | − 10·54 | 0·87 |
| 30 | − 2·46 | 80 | + 0·39 | 130 | − 5·27 | 180 | − 10·82 | |
| 40 | − 1·62 | 90 | − 0·00 | 140 | − 7·04 | | | |

No. 2.—$v=\frac{1}{30}$.

| $\phi$ | R | $\phi$ | R | $\phi$ | R | $\phi$ | R | $a\frac{v^2}{4}\tan\alpha$ |
|---|---|---|---|---|---|---|---|---|
| 0° | − 1·24 | 50° | + 2·93 | 100° | − 2·87 | 150° | − 23·10 | |
| 10 | − 0·43 | 60 | + 3·33 | 110 | − 6·49 | 160 | − 26·08 | |
| 20 | + 0·21 | 70 | + 3·07 | 120 | − 10·65 | 170 | − 27·98 | 3·49 |
| 30 | + 1·12 | 80 | + 1·98 | 130 | − 15·08 | 180 | − 28·64 | |
| 40 | + 2·11 | 90 | 0·00 | 140 | − 19·31 | | | |

No. 3.—$v = \frac{1}{20}$.

| $\phi$ | R | $\phi$ | R | $\phi$ | R | $\phi$ | R | $a\frac{r^2}{4}\tan\alpha$ |
|---|---|---|---|---|---|---|---|---|
| 0° | + 9·49 | 50° | + 11·13 | 100° | − 6·13 | 150° | − 43·77 | |
| 10 | + 9·67 | 60 | + 10·23 | 110 | − 13·33 | 160 | − 49·02 | |
| 20 | + 10·16 | 70 | + 8·15 | 120 | − 21·23 | 170 | − 52·36 | 7·86 |
| 30 | + 10·76 | 80 | + 5·46 | 130 | − 29·32 | 180 | − 53·50 | |
| 40 | + 11·20 | 90 | + 0·00 | 140 | − 37·03 | | | |

No. 4.—$v = \frac{1}{15}$.

| $\phi$ | R | $\phi$ | R | $\phi$ | R | $\phi$ | R | $a\frac{r^2}{4}\tan\alpha$ |
|---|---|---|---|---|---|---|---|---|
| 0° | + 26·60 | 50° | + 23·83 | 100° | − 10·56 | 150° | − 70·53 | |
| 10 | + 26·64 | 60 | + 20·63 | 110 | − 22·57 | 160 | − 78·58 | |
| 20 | + 26·66 | 70 | + 15·70 | 120 | − 35·33 | 170 | − 83·66 | 12·45 |
| 30 | + 26·44 | 80 | + 8·83 | 130 | − 48·12 | 180 | − 85·40 | |
| 40 | + 25·63 | 90 | 0·00 | 140 | − 60·13 | | | |

No. 5.—$v = \frac{1}{12}$.

| $\phi$ | R | $\phi$ | R | $\phi$ | R | $\phi$ | R | $a\frac{r^2}{4}\tan\alpha$ |
|---|---|---|---|---|---|---|---|---|
| 0° | + 50·72 | 50° | + 41·02 | 100° | − 16·28 | 150° | − 103·44 | |
| 10 | + 50·50 | 60 | + 34·53 | 110 | − 34·22 | 160 | − 114·80 | |
| 20 | + 49·76 | 70 | + 25·60 | 120 | − 52·95 | 170 | − 121·93 | 19·46 |
| 30 | + 48·44 | 80 | + 14·08 | 130 | − 71·46 | 180 | − 124·40 | |
| 40 | + 45·42 | 90 | 0·00 | 140 | − 88·66 | | | |

P.S.—I have said that the devices for gaining a large field in achromatic combinations for photography are not available with the reflector. Of course there is no possibility of combining curves, and the other means is the use of a diaphragm to exclude from acting those parts of the surface which cause most diffusion. The position of this diaphragm should be so chosen that it flattens the field—that is, that the centre of the acting surface for oblique rays will have its focus in the plane perpendicular to the axis and passing through the principal focus.

Suppose we desire that this shall be the case for rays inclined to the axis. If we make $x_1$ in the formula giving the distance of this focus from the vertex $= a$, we shall have—

$$v^3 + 6v^2 \tan\alpha - 12v - 8\tan\alpha = 0.$$

When $\alpha$ is small one root is very nearly $\frac{2}{3}\tan\alpha$, and can readily be determined; the other roots are large, one being positive, and the other negative. Practically $v = \frac{2}{3}\tan\alpha$ will be a sufficient approximation to the useful root. The place of the diaphragm will be $av\cot\alpha + a\frac{v^2}{4}$ (sensibly $\frac{2}{3}a$) from the vertex, and this being nearly independent of $\alpha$, it follows that the position flattens the focus for all obliquities. If D be the diameter of the

speculum, then that of the largest opening of the diaphragm will be $D - 2av = D - \frac{4a}{3} \tan \alpha$ for the limiting value of $\alpha$.

If now we assume $\alpha = 2°$ we shall find the diameter of the diaphragm about $43\frac{1}{2}$ inches. The image for the field will be 25·14 inches in diameter, and probably the carriers will require to have a space of 27 inches in diameter allowed for them. This would leave only 28 per cent. of the surface available to form the image of any object; excluding all the central part.

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## *On the Atmospheric Transmission of Visual and Photographically Active Light.* By Captain Abney, R.E., F.R.S.

In his publication, 'Researches on Solar Heat,' which appears in the Professional Papers of the Signal Service, Professor S. P. Langley has been somewhat hard on those astronomers who have made a speciality of observing star-magnitudes. In the report on the transmissibility of our atmosphere for light, in which is embodied the observations made by his party at Mount Whitney, and which appears in the above-named volume, he makes the following remarks: 'For it may be observed in general terms that since the rays with large coefficients are represented by diminishing geometric progression, whose common ratio is near unity, these rays will persist whilst others with small coefficients are very nearly extinguished; and something like this was shown by Biot at the time when Melloni's first observations on the transmission of heat through successive strata attracted attention. But what we desire now further to point out is, that according as the difference of these coefficients of transmission for the different portions of the light of the same star is greater, so will the error of the result in treating them as equal be larger—a consequence so obvious that it is only necessary to make the statement in order to have its truth recognised.

'Since it has now been demonstrated that the formula ordinarily employed leads to too small results, it might properly be left to those who still employ it to show that their error is negligible; but this has never been done. There is possibly an impression that if there were any considerable error its results would become apparent in such numerous observations as have been made all over the world in stellar photometry during this century. But it is, in my opinion, a fallacy to think so; and I believe, as I have elsewhere tried to show, that the error might be enormous; that the actual absorption *might* be twice what it is customarily taken, or 40 per cent. instead of 20 per cent., without the error being detected by such observations as are now made.'

In a paper which I have recently communicated to the Royal Society, on the transmission of sunlight through our atmosphere, I

have described in detail observations which I have carried out during the past year on this subject, using the visible solar spectrum for the particular object I had in view. My wish was to ascertain the loss of luminosity of each visible ray after transmission through varying atmospheric thicknesses. The definite conclusion which I came to was that, as a rule, the loss of light followed Lord Rayleigh's law for scattering by small particles—

$$I' = I\epsilon^{-kx\lambda^{-4}},$$

where I′ and I are the transmitted and original intensities, $x$ the thickness of air, and $\lambda$ the wave-length. These observations which I made it is needless to describe again in this note; suffice it to say they were made by means of the colour photometer described by General Festing and myself last year in the Bakerian lecture. My standard luminosity curve was one taken at 8,500 feet altitude in the Alps, and, as I have already said, nearly every curve of luminosity through other air thicknesses obeyed the above law. Now, having got this result, it was easy to construct curves of luminosity of the spectrum for 1, 2, 3, . . . &c. air thickness in which the ordinates were the relative intensities of the rays transmitted. The areas of such curves when constructed could very easily be found, and such areas would represent the total luminosity of white light coming from the Sun though with varying thicknesses. It would then be easy to see what variation from the law usually employed in stellar observations would occur, and which, according to Langley, would be serious. The law in question is that—

$$I' = Ia^{\sec\theta},$$

I′ and I being the transmitted and original intensities and $a$ the coefficient of transmission, $\theta$ being the zenith distance, the secant of which, within certain limits, is a measure of the air thickness. I found that the minimum value of $k$ in Lord Rayleigh's formula was ·0013, when the value of $\lambda^{-4}$ for $\lambda$=6000 was taken as 78·3. In this case the areas of the curves representing 0, 1, 2, 3, 4, and 5 atmospheres were represented as 761, 662, 577, 504, 439, and 385 respectively. It may be supposed that an observer when observing sunlight integrally would have obtained the same values, and then attempted to adapt the formula just given to it. Probably he would have used 'least squares,' and arrived at a result, but it would hardly have been necessary to do so. I had first omitted to calculate the area of the curve of the spectrum through 5 atmospheres, and I simply took 0 and 4 atmospheres as lying on the curve by the formula—

$$I' = I\epsilon^{-\mu x},$$

where $\mu$ is the coefficient of absorption, and in which $\epsilon^{-\mu} = a$ in the above formula. From this I found that $\mu$=·1378, and this

gave for 1, 2, and 3 atmospheres 664, 578, and 504, the results from the spectrum being 662, 577, and 504. Calculating next the absorption through 5 atmospheres, I found it to be 383 instead of 385. The coefficient of transmission in the usual formula from the above is $a = \cdot 862$, a somewhat high value; but it must be recollected it was my maximum value. Taking a larger value of $k$, viz. $k = \cdot 0019$, the areas for 0, 1, 2, 3, and 4 atmospheres were 917, 755, 623, 513, 418. Taking the first and last as lying on the logarithmic curve, the values obtained were 917, 755, 626, 508, 418, a very close approximation, $\mu$ being $\cdot 19708$, and the coefficient of transmission being $\cdot 822$. I may mention that with any value for $k$ that I tried the same result held good. It thus appears that the logarithmic formula is more than a close approximation to the truth with the values arrived at from my observations.

Professor Langley's values and my own for the transmissibility of the different visible rays differ somewhat, so it occurred to me that it would be right to take his own values for transmissibility, and treat them in the same manner. Taking my Riffel observations of the luminosity of the spectrum as correct, I calculated from them the value of the areas of the curves of luminosity, using Langley's own coefficients of absorption. They were as follows, 1, 2, 3, 4, and 5 atmospheres, 657, 392, 235, 142, and 52. Taking 1 and 4 atmospheres as being on the logarithmic curve, the values derived from the formula were 657, 394, 237, 142, and 51, $\mu$ being $\cdot 5106$ and $a$ being $\cdot 602$; a value which is extremely low.

This shows that still the agreement is complete between them. It must be borne in mind that in observations such as these, which are for settling stellar magnitudes, there is no desire to know the intensity of light outside our atmosphere. All that concerns the astronomer is to compare light coming from a star at the zenith with that coming from it at a reasonable zenith distance; 5 atmospheres is represented by a Z.D. of about $78° 30'$, and it is unlikely that anyone would set much value on observations made at a greater Z.D. than that. Hence for the comparison of star magnitudes the usual formula may safely be adopted. A much more serious matter is the absorption coefficient used, and we find that it varies between $\cdot 791$ and $\cdot 843$, according to previous observations, whilst I have found my maximum at sea level to be $\cdot 869$, though my mean is not far from the $\cdot 825$, which value has been adopted by some astronomers.

The Z. distances of two observed stars may vary very greatly. This discrepancy of course would alter the calculated magnitudes very considerably, but if the difference be small the calculated magnitude will not be far out, even if the absorption coefficient be a little out from the truth. I may remark that in taking his stellar magnitudes, Professor Pritchard seems to have taken every care as to this, his comparison star being *Polaris*, and the star observed being about the same zenith distance.

Having arrived at the conclusion regarding visual observation, it struck me that absorption of the photographic spectrum ought to follow the same course. Now in the 'Proceedings of the Royal Society' I have given a very careful measurement of the photographic sensitiveness to various rays of light of bromo-iodide of silver, besides which I had the spectrum sensitiveness of other salts of silver by me, and I knew the air thickness and the spectral luminosity on the day when these measures were taken. Assuming that the ultra violet rays obeyed the same law as the visible rays, it was easy to calculate the photographic value of each ray for any air thickness; and this I accordingly did.

Using a value of ·00183 for $k$ in Lord Rayleigh's formula, the same process as before was gone through, supposing a plate of bromo-iodide of silver had been used: the areas were for 0, 1, 2, 3, and 4 atmospheres, 835, 621, 457, 340, and 254. The values arrived at by the logarithmic formula were 837, 621, 461, 342, and 254. This gave $\mu = \cdot 2980$, and the coefficient of transmission, ·742.

Taking chloride of silver as the sensitive salt, its spectrum value being known, and proceeding as before, the following areas were found for 0, 1, 2, 3, and 4 atmospheres: 693, 413, 246, 147, and 87. Calculated by the logarithmic formula, they became 689, 413, 248, 148, and 87, $\mu = \cdot 5115$, and the coefficient of transmission $= \cdot 603$.

Taking these two results it is evident that before any definite knowledge of a value of a star magnitude by photography can be arrived at (supposing all stars were of the same colour) a definite acquaintance must be made with the kind of sensitive salt that is employed. Thus the bromo-iodide plate gave a value of transmission of ·742; the chloride, of ·603; whilst the optical value was only ·880 when $k = 001183$.

Now it may be considered that these results are only theoretical deductions, but luckily they are capable of proof in the laboratory by experiment.

Water can easily be made turbid by alcoholic solutions of mastic or by other fine precipitates, and last year General Festing and myself proved that these artificially prepared turbid media strictly obeyed Lord Rayleigh's law. Now it was easy, having proved this, to ascertain whether when the light passing through such media was measured integrally by optical and photographic means the logarithmic formula was followed.

Experiment showed that it did so. Here is one of several results. A cell measuring exactly 6 inches by 4 inches was taken, and the values of light passing through these thicknesses of clear and turbid water were found to be—

| | 4-in. | 6-in. |
|---|---|---|
| Clear ... ... ... ... | 75·6 | 75·4 |
| Turbid ... ... ... ... | 26·5 | 15·5 |

Taking the clear or incident light as the mean of the two, 75·5, and using the 6 inches of the turbid medium as lying on the curve, the logarithmic formula gave $\mu = \cdot 2639$ in the formula

$$I' = I\epsilon^{-\mu x},$$

and the absorption consequently for 4 inches of the fluid $= 26 \cdot 3$.

Taking the photographic values a bromo-iodide plate was exposed to the clear, the 4-inch and the 6-inch turbid water for definite times, and the values of the light acting on the plate found to be

$$\text{4-inch clear} \quad 1$$

$$1 - \text{4-inch turbid} \quad \frac{1}{10 \cdot 125}$$

$$\text{6-inch turbid} \quad \frac{1}{33 \cdot 1}$$

Using the logarithmic formula as before, taking the clear and 6-inch turbid light as lying on the curve, the value of the 4-inch turbid would be $\frac{1}{10 \cdot 3}$, and the value of $\mu = \cdot 5832$.

The optical value of $\mu$ is 2·639. The ratio of the optical to the photographic value of $\mu$ is 1 : 2·21, as determined by experiment.

Taking the optical and photographic values of $\mu$, say, for a value of $k = \cdot 001183$, they are ·1324 and 2980, or 1 : 2·25.

This shows, I think, that the values of $\mu$ determined experimentally in the laboratory and by appeal to the atmosphere are as consistent as can be expected.

Further we have this curious fact, that if we take the optical value of unanalysed light passing through the atmosphere, and also the photographic value of the same, we are able to form two equations which give the value of $k$, which must be applied to every wave-length, and also enable a curve of light to be constructed which takes into account general absorption by mist which is not composed of sufficiently fine particles to scatter light. Calculation shows that $k$ is derived from either by dividing $\mu$ by 110 and 250 respectively when $k$ is less than ·0013. These gradually alter in value till they become 104 and 255, when $k = \cdot 0015$ is reached. The values of 110 and 255 are inverse fourth power of wave-lengths in the green and violet respectively, showing that when light is integrally measured it is equivalent to measuring definite rays in these parts of the spectrum.

I have not touched upon the question of how star magnitudes are to be measured, but merely ventured to give a means of applying a correction for loss caused by the atmospheric transmission. It will be seen how much greater is the loss of those rays which are photographically active than the visual rays, and it would appear that to enable a proper correction to be

made to photographs of stars taken at different times, the visual absorption at the time should also be calculated. I am not alluding now to the fact that the angle included in any star photograph is small; stars on such a plate may be compared *inter se*; but in order to make comparisons general the atmospheric absorption for the photographically active rays must be studied, and it is absolutely necessary that the spectrum value of the sensitive salt should be known beforehand.

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*Photographic Search for the Minor Planet Sappho.*
By Isaac Roberts.

From 1872 to the present time no observations of the minor planet *Sappho* have been published except those of 1882, in which year Mr. Gill took measures for a determination of the solar parallax.

Mr. Bryant, who is engaged in determining the orbit of this planet, prepared an ephemeris for the opposition of this year, and in order that no time might be lost in identifying it from the neighbouring faint stars, and further that the error of the ephemeris might be obtained as early as possible, he sent, on December 16, 1886, the positions he had calculated, and appealed to me to find the planet if possible by photography.

The brightness of the planet is estimated at eleventh magnitude, and since its orbital movement in sixty minutes is equal to about 4·2 times its photographic diameter, the trail it would leave would probably not exceed in density a thirteenth magnitude star.

On December 30 I obtained, with an exposure of sixty minutes between sidereal time at Maghull, $7^h\ 35^m$ and $8^h\ 35^m$, a negative of which the accompanying photograph marked chart No. 1 is an enlargement to three diameters. The trail of the planet is to be seen near the centre, and to make it more easily recognisable a white circle is drawn round it.

Another photograph was taken on January 1, and a third on the 14th. These are marked respectively charts Nos. 2 and 3. Each of the three charts shows the difficulties to be encountered in finding a planet so faint as this one amongst such numbers of other faint stars, and as an illustration I may refer to chart No. 3 upon which I estimate that there are about 2,000 stars below the seventh magnitude on each square degree.

Mr. Bryant informs me that the error of the ephemeris deduced from the photographs is in very close agreement with that from two meridian observations of the planet made about the same time at Dunecht, results that must be considered satisfactory.

This is probably the first instance in which photography has been successfully applied to the purpose here described, and as an historical fact it may be worth recording. There are also

some inferences which might be drawn from these experiments. First, it is here demonstrated that asteroids of eleventh magnitude leave very strong trails on the films of the photographic plates, and probably others down to the thirteenth or fourteenth magnitude could under favourable atmospheric conditions be photographed.

Another inference is that all the asteroids which up to the present time have been discovered, together with those that may exist but are not recorded down to the fourteenth magnitude, could by one astronomer alone be found and accurately charted in the course of two or three years' time.

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## *On the Orbit of* 14 (*i*) *Orionis* (*O. Struve* 98). By J. E. Gore.

I have computed the orbit of this binary star by means of the graphical method, and find the following provisional elements :—

*Elements of* 14 (*i*) *Orionis.*

| | |
|---|---|
| $P = 190{\cdot}48$ years | $\Omega = 99^\circ\ 35'$ |
| $T = 1959{\cdot}05$ A.D. | $\lambda = 302^\circ\ 42'$ |
| $e = 0{\cdot}2465$ | $a = 1''{\cdot}22$ |
| $\gamma = 44^\circ\ 57'$ | $\mu = -1^\circ{\cdot}89$ |

From these elements we have the following formulæ :—

$$(1)\quad u - 14^\circ{\cdot}12 \sin u = -1^\circ{\cdot}89\,(t - 1959{\cdot}05)$$

$$(2)\quad \tan \tfrac{1}{2}V = 1{\cdot}286 \tan \tfrac{1}{2}u.$$

$$(3)\quad \tan(\theta_c - 99^\circ\ 35') = 0{\cdot}7077 \tan(V + 302^\circ\ 42')$$

$$(4)\quad \rho = 1''{\cdot}22\,(1 - 0{\cdot}2465 \cos u)\,.\,\frac{\cos(V + 302^\circ\ 42')}{\cos(\theta_c - 99^\circ\ 35')},$$

where $u$ is the excentric anomaly, and V the true anomaly for the epoch $t$; $\theta_c$ the required position-angle, and $\rho$ the distance.

The following is a comparison between the recorded measures and the positions computed from the above elements :—

| Epoch. | Observer. | $\theta_o$ | $\theta_c$ | $\theta_o - \theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o - \rho_c$ |
|---|---|---|---|---|---|---|---|
| | | ° | ° | ° | " | " | " |
| 1844·05 | Mädler | 258·8 | 254·44 | +4·36 | — | 1·36 | — |
| 1844·53 | O. Struve | 250·83 | 253·95 | −3·12 | 1·14 | 1·35 | −0·21 |
| 1849·22 | „ | 249·60 | 248·97 | +0·63 | 0·98 | 1·33 | −0·35 |
| 1852·15 | Mädler | 245·4 | 245·80 | −0·40 | — | — | — |
| 1854·82 | Dawes | 240·9 | 242·75 | −1·85 | 1·29 | 1·29 | 0·00 |
| 1859·22 | O. Struve | 237·80 | 237·55 | +0·25 | 1·24 | 1·26 | −0·02 |
| 1865·98 | Dembowski | 234·0 | 228·95 | +5·05 | 1·25 | 1·20 | +0·05 |

| Epoch. | Observer. | $\theta_o$ | $\theta_c$ | $\theta_o - \theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o - \rho_c$ |
|---|---|---|---|---|---|---|---|
| | | ° | ° | ° | " | " | " |
| 1867·15 | Dembowski | 232·1 | 227·4 | +4·70 | 1·28 | 1·19 | +0·09 |
| 1868·14 | " | 228·5 | 226·1 | +2·40 | 1·05 | 1·18 | −0·13 |
| 1869·19 | Dunér | 224·6 | 224·63 | −0·03 | 0·95 | 1·17 | −0·22 |
| 1870·81 | Dembowski | 223·3 | 222·25 | +1·05 | 1·21 | 1·16 | +0·05 |
| 1870·87 | O. Struve | 224·13 | 222·17 | +1·96 | 1·09 | 1·16 | −0·07 |
| 1873·42 | Dembowski | 219·2 | 218·45 | +0·75 | 1·26 | 1·14 | +0·12 |
| 1876·18 | Dunér | 211·9 | 214·25 | −2·35 | 1·22 | 1·11 | +0·11 |
| 1876·88 | Dembowski | 212·8 | 213·17 | −0·37 | 1·11 | 1·11 | 0·00 |
| 1877·18 | Schiaparelli | 209·9 | 212·71 | −2·81 | 0·98 | 1·10 | −0·12 |
| 1878·35 | Dembowski | 208·2 | 210·8 | −2·60 | 0·99 | 1·10 | −0·11 |
| 1879·10 | Hall | 205·8 | 209·61 | −3·81 | 0·89 | 1·09 | −0·20 |
| 1880·14 | Jedrzejewicz | 209·1 | 207·91 | +1·19 | 1·03 | 1·08 | −0·05 |
| 1881·13 | Hall | 203·2 | 206·28 | −3·08 | 1·03 | 1·07 | −0·04 |
| 1881·16 | Jedrzejewicz | 205·9 | 206·23 | −0·33 | 1·08 | 1·07 | +0·01 |
| 1882·14 | " | 201·3 | 204·62 | −3·32 | 1·00 | 1·06 | −0·06 |
| 1882·76 | Engelmann | 203·3 | 203·53 | −0·23 | 1·15 | 1·06 | +0·09 |
| 1886·917 | Tarrant | 196·4 | 196·15 | +0·25 | 1·13 | 1·04 | +0·09 |
| 1886·977 | " | 195·8 | 196·11 | −0·31 | 1·16 | 1·04 | +0·12 |
| 1887·019 | Young | 195·5 | 196·07 | −0·57 | 0·98 | 1·04 | −0·06 |

The magnitudes of the components are about 6 and 7. According to the above elements the distance will remain nearly constant during the next fifty years, the angle diminishing to about 107° in the year 1936. As far as I know the orbit has not been previously computed. Some of the measured angles in late years are very discordant. Professor Young's measure this year was communicated to me by private letter.

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## *Observations of the Variable Star S (10) Sagittæ.*
By J. E. Gore.

The following are my observations of this interesting variable star in the year 1886. They form a continuation of the observations given in the *Monthly Notices* for January 1886.

The comparison stars are, as before:—

| | Mag. |
|---|---|
| 11 *Sagittæ* ... ... ... ... | 5·8 |
| 9 *Sagittæ* ... ... ... ... | 6·6 |
| DM + 16°, 4086 ... ... ... | 7·0 |

*Observations of* 10 *Sagittæ.*

| Date. | | h m | Mag. | Date. | | h m | Mag. |
|---|---|---|---|---|---|---|---|
| 1886, Jan. | 6 | 5 45 | 5·7 | 1886, Sept. | 30 | 10 25 | 6·2 |
| | 13 | 6 0 | 6·4 | | 30 | 11 20 | 6·1 |
| May | 19 | 10 25 | 6·1 | Oct. | 1 | 7 55 | 5·7 |
| | 21 | 10 50 | 5·8 | | 1 | 10 40 | 5·7 |
| | 22 | 10 15 | 5·9 | | 7 | 9 30 | 6·4 |
| | 26 | 10 30 | 6·4 | | 9 | 7 10 | 6·0 |
| | 31 | 10 45 | 5·9 | | 10 | 6 45 | 5·7 |
| June | 12 | 10 30 | 6·4 | | 12 | 7 5 | 5·7 |
| July | 12 | 10 15 | 5·8 | | 13 | 10 10 | 5·9 |
| | 19 | 10 0 | 5·7 | | 16 | 7 15 | 6·3 |
| | 21 | 9 45 | 5·9 | | 21 | 10 54 | 5·9 |
| | 22 | 10 10 | 6·1 | | 23 | 6 45 | 6·4 |
| Aug. | 8 | 9 15 | 6·4 | | 23 | 10 30 | 6·4 |
| | 14 | 9 0 | 5·9 | | 24 | 6 26 | 6·4 |
| | 22 | 8 40 | 5·8 | | 25 | 9 57 | 6·2 |
| | 28 | 9 0 | 5·9 | | 26 | 6 37 | 5·8 |
| | 29 | 8 15 | 5·8 | | 26 | 10 40 | 5·85 |
| | 31 | 8 20 | 5·7 | | 28 | 7 7 | 5·9 |
| Sept. | 1 | 10 45 | 6·0 | | 31 | 6 20 | 6·1 |
| | 2 | 8 25 | 6·15 | Nov. | 1 | 8 40 | 6·4 |
| | 3 | 8 20 | 6·2 | | 3 | 6 56 | 6·0 |
| | 5 | 8 42 | 6·0 | | 4 | 9 30 | 5·65 |
| | 6 | 7 58 | 5·8 | | 5 | 7 50 | 5·75 |
| | 6 | 11 35 | 5·7 | | 8 | 6 45 | 6·25 |
| | 8 | 8 25 | 5·8 | | 10 | 8 0 | 6·4 |
| | 14 | 10 2 | 5·8 | | 16 | 5 50 | 6·1 |
| | 15 | 7 40 | 5·7 | | 17 | 5 43 | 6·25 |
| | 16 | 7 50 | 5·85 | | 23 | 5 27 | 5·8 |
| | 17 | 7 55 | 5·8 | | 26 | 5 30 | 6·3 |
| | 18 | 7 40 | 6·0 | | 30 | 8 15 | 5·9 |
| | 18 | 11 20 | 6·05 | Dec. | 4 | 5 26 | 6·4 |
| | 20 | 8 10 | 6·4 | | 12 | 6 10 | 6·2 |
| | 20 | 11 0 | 6·4 | | 16 | 5 22 | 5·6 |
| | 22 | 7 10 | 5·9 | | 22 | 5 4 | 6·35 |
| | 25 | 11 30 | 5·9 | | 24 | 6 25 | 5·8 |
| | 27 | 7 5 | 6·2 | | 25 | 5 30 | 5·65 |

## *A Proposed Nomenclature for Star Colours.* By W. S. Franks.

It is generally admitted that the nomenclature of star colours is at present in a very unsatisfactory state, and not at all in keeping with the exact methods employed in other departments of astronomical observation. The hitherto popular fashion of naming star tints after fruit, flowers, precious stones, &c., is both vague and arbitrary, and also objectionable on account of the frequent diversity in tint of the object referred to. Any standard whatever, to be of real utility, must be readily accessible and also of uniform tint—the same at all times and in all places. It is very evident that the terrestrial objects just mentioned do not fulfil any one of these conditions; and so they should now be definitely rejected, as their retention only serves to perpetuate the existing confusion. The late Admiral Smyth, who was doubtless responsible for the introduction of many of these poetic but exceedingly vague terms, felt the force of the objections to their use, when he wrote the brochure entitled "Sidereal Chromatics"—a book which was unfortunately only intended for private circulation, and therefore not so well known as it deserves to be. It contained a plate of coloured discs, with four gradations each of red, orange, yellow, green, blue, and purple, which was intended as a scale upon which star colours could be more definitely expressed. But this chromatic diagram, pretty as it looked, had several serious faults. Its twenty-four tints were not so carefully selected as they might have been, nor, indeed, were they sufficient to meet the requirements of the observer; and further, an opaque wafer of colour, necessarily viewed by artificial light (which of course modified its appearance), could not well be compared with a glittering stellar point. The successive depths of tint, also, were inversely put with regard to the numerical order. Thus, the deepest tint of red was called "Red $^1$," and the palest "Red.$^4$" Some of the colours themselves are open to criticism. For instance, the two deeper shades of orange are not pure, but have a perceptible tinge of red, whilst the two corresponding shades of yellow are really orange-yellow. Neither the red nor the green are typical colours, as anyone may see by comparing them with the ordinary daylight spectrum; the former is too crimson, and the latter too bluish-green. There is some reference to the colours of stars in Professor Piazzi Smyth's "Madeira Spectroscopic," and a chromo-lithograph at the end of that work gives a graduated series of primary, secondary, and tertiary spectrum colours, with their corresponding wave-numbers.

It is pretty evident that, in the future, we must look to the spectrum for our standard colours. But as these star observations are confined to the period when the sun is below the horizon, it is equally obvious that they cannot be directly so

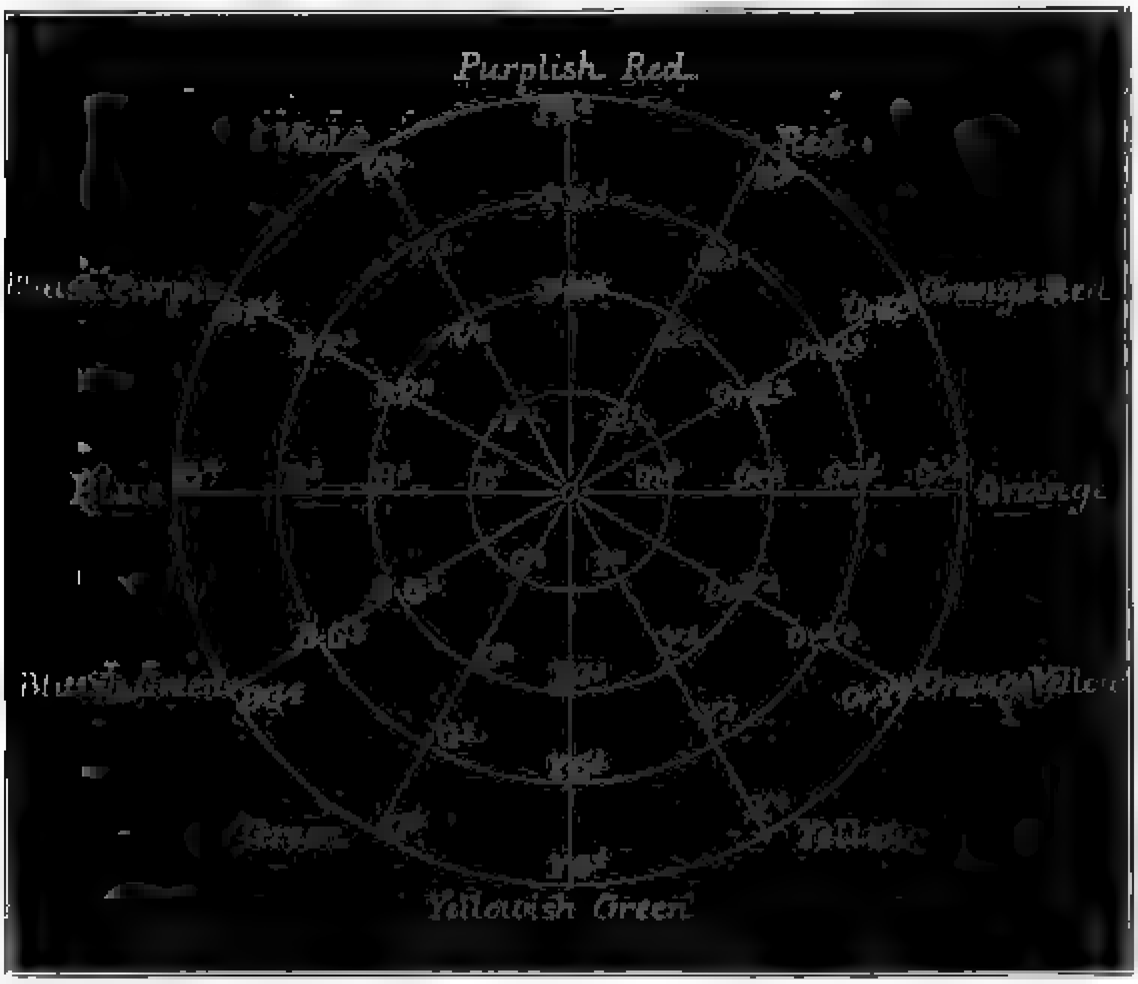
compared. This difficulty might be, however, got over by having a series of coloured gelatine discs carefully matched with the spectrum, and then viewing them as transparencies by the light transmitted from an incandescent electric lamp. In attempting to devise any plan for the more systematic observation of star colours, there are several essential points to be considered. The standard must be uniform, and easily accessible anywhere for reference, if it is to meet with universal adoption. The solar spectrum answers this end completely, since it affords a well-marked range of colours, which can be expressed in wave-lengths, or referred to certain Fraunhofer lines. The nomenclature should be as simple as possible, yet copious enough for ordinary requirements, and be arranged on some methodical plan, so as to be easily remembered. Its terms should have a precise and definite meaning, and be capable of numerical reduction, so as to get mean results from a number of observations. How far these conditions are fulfilled in the scheme which I have the honour to lay before the Society may be best judged of by reference to the annexed diagram. The germ of the present plan is due to certain suggestions made by Professor Pickering, that I should reject all modifications of white, as applied to stars, except in the direction of the prismatic colours, and that I should take white as one end of a series for each colour, giving a numerical ratio to each term in the series. It then occurred to me to call white the zero, from which the spectral colours radiate as a centre, each concentric ring corresponding to a given depth of each colour. Starting with red, the primary and subordinate colours are placed at equal distances round the circle up to violet, and the opposite ends of the spectrum connected by the intermediate tint of purplish red. On this plan, too, each colour is opposite to its complementary; the sum of any two opposite colours forming white light. This may be convenient in estimating the colours of "double" stars. As to the fiducial points to which the chief colours are referred I would, provisionally, adopt Professor Smyth's definition of them. They would then run as follows :—

| | | | |
|---|---|---|---|
| Red ... ... | * WN 36,000 : | Nearest Solar lines | a and B. |
| Orange ... ... | „ 40,000 : | „ „ | α (alpha). |
| Yellow ... ... | „ 43,000 : | „ „ | $D^1$ and $D^2$. |
| Green ... ... | „ 49,000 : | „ „ | $b^1$, $b^2$, &c. |
| Blue ... ... | „ 56,000 : | „ „ | d. |
| Violet ... ... | „ 60,000 : | „ „ | G and g. |

With regard to the *names* of the colours, I have tried to avoid even such terms as "citron," "glaucous," &c., because, though used by Professor Smyth, they would certainly be misinterpreted by many observers. In adopting Professor Picker-

* The wave-number is for the *centre* of each colour.

ing's restriction of "white," I have sacrificed all such qualifying adjectives as very, intense, pale, greyish, &c., for, as generally used, these refer to the relative *brightness* of the light rather than to its colour. The terms I have proposed for the subordinate tints carry their own meaning, as they are compounded of the two adjacent primaries. And, by inverting the order, a minuter subdivision might be made, exactly analogous to the case of star magnitudes; as we could divide the interval between green and blue, say, into "bluish-green" and "greenish-blue," according to whether green or blue was the strongest component. But probably there would be no necessity for this, as the number of tints (forty-eight in all) seems sufficient for




the required purpose, and is twice as many as the number on Smyth's chromatic diagram. Commencing, now, with the centre as "white" (see diagram), the symbol for which is "0": the first circle will represent ruddy white, creamy white, yellowish white, greenish white, bluish white, and purplish white, their symbols being $R^1$, $Or^1$, $Y^1$, $G^1$, $B^1$, and $V^1$: the next circle *pale* red, *pale* orange, *pale* yellow, &c.; symbols, $R^2$, $Or^2$, $Y^2$, &c.: the succeeding circle is intended to be equivalent to the *normal* shade of red, orange, yellow, &c.; symbols, $R^3$, $Or^3$, $Y^3$, &c.: the outer circle corresponds to the deepest shades of colour, as *very* red, *very* orange, *very* yellow, &c.; symbols, $R^4$, $Or^4$, $Y^4$, &c. Thus the four terms in each series

are supposed to be equal to four corresponding increments of depth of shade, the numerical ratios being *direct*, instead of *inverse*, as in Smyth's scale. And it is at once apparent how readily these terms admit of reduction in discussing a number of observations. I have not thought it necessary to specify the subordinate colours here, as their corresponding symbols appear on the diagram. But though they all follow the same invariable rule—that is, the *inner* circle means *white tinged* with the given colour: circle 2, a *pale* tint of the colour; circle 3, the *normal* colour; and circle 4, the *deepest* tint of colour, yet it will not, in all probability, be requisite to use the first term in their series, as six different tints of white are as many as can be well distinguished from each other.

P.S.—The original diagram, of which the annexed is a copy, was executed in water-colours, and gives a much better idea of the proposed scheme than one in black and white can possibly do, but it would probably be difficult and expensive to reproduce in a satisfactory manner.

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## *On the Best Device for Revolving a Dome.* By Professor David P. Todd.

(*Communicated by the Secretaries.*)

The various methods which have been devised for applying power to revolve a dome show that it is a matter of considerable importance in observatory construction. The number of these methods shows also that many of them, at least, are imperfect either in principle or construction. A very common method, especially in the older observatories, consists of a continuous rachet or cog-wheel run around the bed-plate or interior of the dome, in which a cog-wheel on a short journal runs, the power being communicated to this latter in the simplest manner. The difficulties in the way of this device consist rather in the imperfection of the running-gear of the dome itself. In constructing the large dome of the Washburn Observatory, at Madison, Wisconsin, the late Professor Watson sought to overcome these difficulties by a double cog-wheel, which should work into the rachet of the dome on exactly opposite sides of the latter. In order to secure this end, a somewhat cumbersome apparatus was devised and applied, consisting of two vertical shafts on opposite sides of the dome geared into a rigid horizontal shaft, running across from one side to the other, underneath the floor of the dome. This apparatus is described in Vol. I. of the publications of this Observatory. In constructing the smaller dome of the Lick Observatory, the idea occurred to Mr. Fraser, the superintendent of construction, that the dome itself might be considered as a large pulley, and a rope run around it as such, and brought into the inside of the dome, where it was carried around a suitable

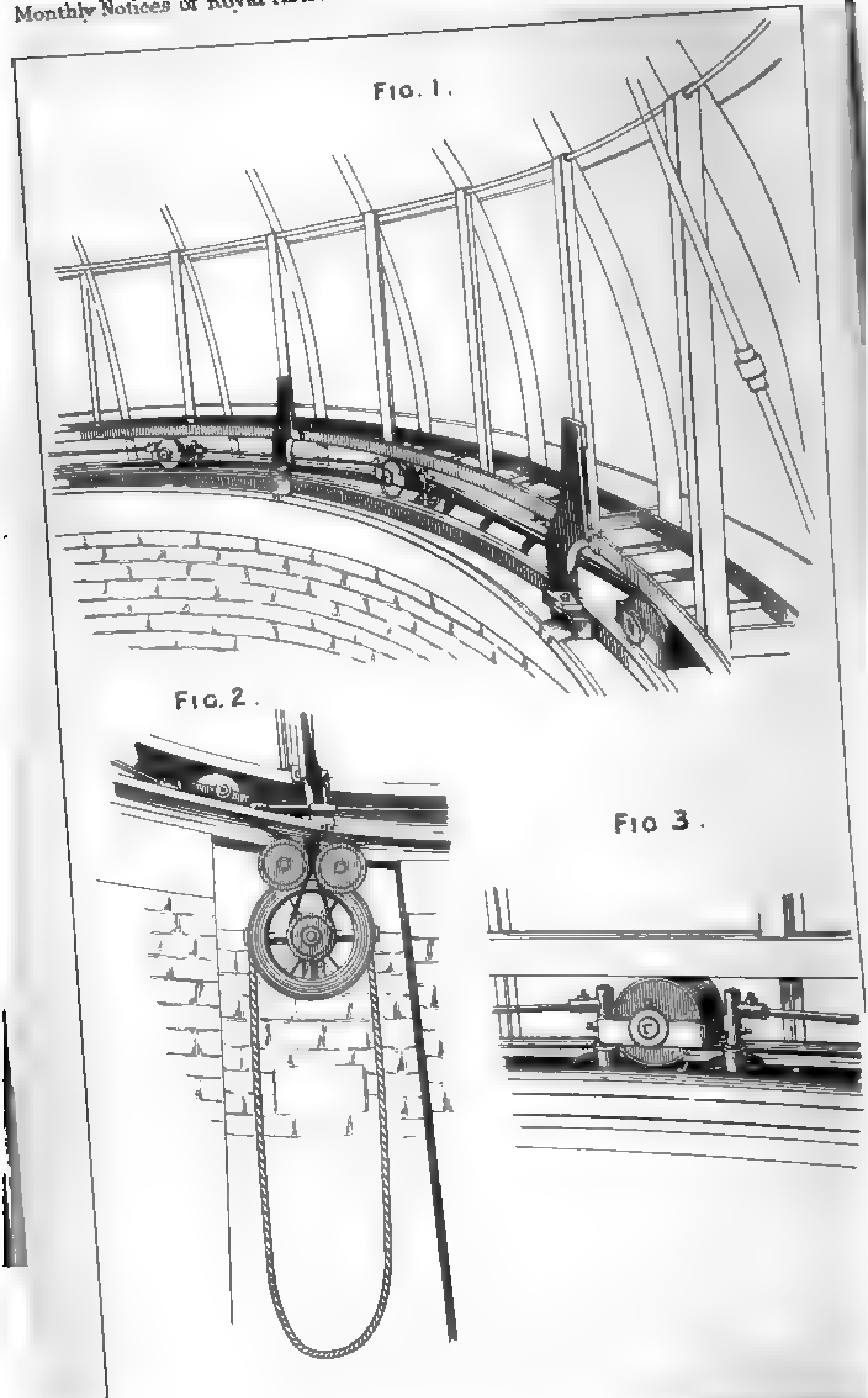
FIG. 1.
FIG. 2.
FIG. 3.

pulley connected with the gearing and a crank. This device works in the most perfect manner, and there is no objection to it except that, the rope being run around the outside of the dome, it is not easy to secure perfect weather protection at the point where the rope passes to the inside of the dome. In addition to this, the rope itself where exposed on the exterior of the dome would require protection from the weather, especially in our northern latitudes.

When Mr. Warner, of the firm of Warner and Swasey, of Cleveland, was at the Lick Observatory in May last, the idea occurred to him that the wire rope employed in turning the dome could, by means of a suitable device, be run around the inside of the dome quite as well as the outside, thus rendering special weather protection unnecessary, and reducing the apparatus to a very compact form. The accompanying plate (figs. 1–3) gives a good idea of this new device as constructed by Mr. Warner for the first time, and applied to the 22-feet dome of the new observatory at Smith College, Northampton. It will be seen that there are attached to the projecting uprights of the dome a series of horizontal grooved pieces, curved to the same radius as that of the dome itself. These pieces form a continuous grooved pulley on the inside of the dome, and concentric with it. Immediately underneath the bed-plate of the dome, and rigidly attached to the wall, is a framework carrying the pulleys as represented in the plate (fig. 2). Around the largest of these pulleys passes an inch rope, to which the necessary power is applied by the hand. On the same axle with this large pulley is a small pulley, around which a wire cable passes which revolves the dome directly. To facilitate the running of the wire rope from this small pulley into the large grooved pulley of the dome itself, a pair of idle pulleys are placed immediately underneath the grooved pulley attached to the dome. As these loose pulleys are placed very near together, they serve also the purpose of giving the rope a larger bearing service upon the motor-pulley below them. It will be seen that the device is a very simple and compact one. It is all contained in a shallow niche in the wall, and is thus entirely beyond the reach of the observing-chair as it moves upon the floor of the dome. The distribution of the power to every part of the circumference of the dome by means of the wire rope is an important advantage not secured in any form of cog-wheel apparatus. The bearing surface of the wire rope upon the dome is nearly 70 feet long; so that, although the rope may be quite loose, there is still friction enough to move the dome readily. The perfection of the running-gear of the dome itself has, of course, much to do with the ease of movement of this revolving apparatus. In the case of the dome alluded to above, a three-pound weight is sufficient to set the dome in motion, the ratio of descent of the weight to the movement of the periphery of the dome itself being about as three to one.

In connection with the accompanying illustration of a section of the running-gear of the dome, the following brief description will make its construction clear. First, being assured that the tracks on the wall-plate and the conical wheels are turned to their exact cones, the next important point is to hold these wheels so that their axes produced will converge to a point at the centre of the tracks. Messrs. Warner and Swasey have found it impossible to accomplish this by any system of bearing of the live ring. They therefore provide a yoke for each conical wheel. In addition to carrying the journals of the conical wheel, each yoke carries also two guide-wheels, which run between the tracks of the wall-plate. These guide-wheels are so adjusted as to keep the axis of the conical wheel coincident with the true radius of the circle of the wall-plate. These guide-wheels obviate also the necessity of flanges on the conical wheels, while the yokes merely require connection with each other by single flexible rods, forming thus the continuous live ring. By these simple devices the friction is so largely reduced that the dome may be readily revolved by the application of a direct tangential pressure of $1\frac{1}{2}$ pound for each ton's weight.

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## *A Centering Tube for Reflecting Telescopes.* By Edward Crossley.

To facilitate the centering of the "Common" 3-foot Reflector I have constructed a tube with diaphragms, by means of which the mirrors can be adjusted with the greatest ease.

The tube I use is 10 inches long and $2\frac{5}{8}$ inches in diameter. This is placed in the eye end at the side of the telescope. The end of the tube towards the eye has a small pin-hole. The other end towards the mirrors has two diaphragms which will replace each other concentrically. The large diaphragm is 1·96 inch in diameter, the small one is 0·37 in diameter. The large diaphragm just embraces the large mirror, which can be centered by means of the flat. The small diaphragm is then put in its place, and the flat centered by means of the adjustment of the large mirror, or, better still, by the adjustment of the eye end.

Thus the telescope can be centered in any position with accuracy during the day or with illumination at night.

The sizes of the diaphragms are proportionate to the diameters of the large and small mirrors respectively, and the length of the tube is a little less in proportion than the focal length so as to embrace a rather larger angle.

At night time a reflector is necessary within the tube at an angle of 45° to the tube, with an opening at the side so as to throw the light of a lamp held in the hand upon the inner face of the diaphragm, and a white sheet of paper stretched on a hoop can be set in front of the telescope and illuminated by another lamp. This, however, is not necessary if the work is properly done in the daytime.

## *Observations of Comets e 1886 (Finlay), b 1887 (Brooks), c 1887 (Barnard), and d 1887 (Barnard) made at the Royal Observatory, Greenwich.*

*(Communicated by the Astronomer Royal.)*

The observations were made with the East or Sheepshanks Equatorial, aperture 6·7 inches, by taking transits over two cross wires at right angles to each other, and each inclined 45° to the parallel of Declination.

| 1887. | Greenwich Mean Solar Time. | Observer. | ☄−* R.A. | Corr. for Par. and Refract. in R.A. | ☄−* N.P.D. | Corr. for Par. and Refract. in N.P.D. | No. of Comp. | Apparent R.A. | Apparent N.P.D. | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Comet e 1886 (Finlay).* | | | | | | | | | |
| | h m s | | m s | s | ′ ″ | ″ | | h m s | ° ′ ″ | |
| Jan. 16 | 7 17 14 | H. | +2 20·30 | +0·20 | −6 42·6 | −6·7 | 2 | 1 3 4·80 | 82 7 53·9 | *a* |
| 25 | 8 21 53 | | −1 28·83 | +0·27 | −5 34·1 | −5·9 | 3 | 1 43 7·73 | 77 33 29·8 | *b* |
| | *Comet b 1887 (Brooks).* | | | | | | | | | |
| Feb. 27 | 10 17 42 | H. T. | +2 32·47 | +0·47 | +4 32·2 | −2·0 | 3 | 3 18 55·03 | 31 46 55·9 | *c* |
| 28 | 9 42 27 | | +2 53·33 | +0·50 | +8 16·1 | −1·5 | 3 | 3 22 31·03 | 32 51 28·0 | *d* |
| | 9 42 27 | | +2 14·00 | +0·50 | +0 29·3 | −1·7 | 3 | | | *e* |
| | *Comet c 1887 (Barnard).* | | | | | | | | | |
| Feb. 28 | 12 32 49 | M. | +1 11·25 | −0·10 | +1 56·9 | −3·3 | 2 | | | *f* |
| | 12 39 31 | H. T. | +1 14·65 | −0·10 | +1 54·5 | −3·3 | 2 | | | *g* |
| | *Comet d 1887 (Barnard).* | | | | | | | | | |
| Feb. 28 | 7 44 0 | H. T. | +0 12·20 | +0·33 | +1 25·7 | −9·2 | 6 | | | *h* |

*Mean Places of Comparison Stars.*

| Star's Name. | R.A. 1887·0. | N.P.D. 1887·0. | Authority. |
|---|---|---|---|
| | h m s | ° ′ ″ | |
| (a) W.B. 0·1043 | 1 0 44·81 | 82 14 37·9 | Glasgow Catalogue, 1875. |
| (b) Arg. Zone + 12°, No. 242. | 1 44 56·64 | 77 39 4·1 | Bonn Observations, vol. vi. |
| (c) Oeltz.-Arg. (N.) 3731 | 3 16 22·43 | 31 42 31·3 | Oeltz.-Arg. (N.) |
| (d) Oeltz.-Arg. (N.) 3772–3 | 3 19 37·50 | 32 43 18·6 | " " |
| (e) Anonymous | | | |
| (f) Arg. Zone + 46°, No. 3148 | 20 58 0 | 43 2 | Bonn Observations, vol. v. |
| (g) Arg. Zone + 46°, No. 3148 | 20 58 0 | 43 2 | " " vol. v. |
| (h) Arg. Zone + 22°, No. 767 | 4 45 56 | 67 3 | " " vol. iv. |

*Notes.*

Jan. 16 and 25. Comet very faint. Feb. 28. Comet extremely faint, partly owing to moonlight.

The observations are corrected for parallax and refraction. The initials H. T., M., and H. are those of Mr. Turner, Mr. Maunder, and Mr. Hollis respectively.

*Royal Observatory, Greenwich:*
1887, *March* 11.

## *Observations of Comets e 1886 (Finlay), b 1887 (Brooks), c 1887 (Barnard), and d 1887 (Barnard) made at the Royal Observatory, Greenwich.*

*(Communicated by the Astronomer Royal.)*

The observations were made with the East or Sheepshanks Equatorial, aperture 6·7 inches, by taking transits over two cross wires at right angles to each other, and each inclined 45° to the parallel of Declination.

| 1887. | Greenwich Mean Solar Time. | Observer. | ☄−✱ R.A. | Corr. for Par. and Refract. in R.A. | ☄−✱ N.P.D. | Corr. for Par. and Refract. in N.P.D. | No. of Comp. | Apparent R.A. | Apparent N.P.D. | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Comet e 1886 (Finlay).* | | | | | | | | | |
| | h m s | | m s | s | ′ ″ | ″ | | h m s | ° ′ ″ | |
| Jan. 16 | 7 17 14 | H. | +2 20·30 | +0·20 | −6 42·6 | −6·7 | 2 | 1 3 4·80 | 82 7 53·9 | *a* |
| 25 | 8 21 53 | | −1 28·83 | +0·27 | −5 34·1 | −5·9 | 3 | 1 43 7·73 | 77 33 29·8 | *b* |
| | *Comet b 1887 (Brooks).* | | | | | | | | | |
| Feb. 27 | 10 17 42 | H. T. | +2 32·47 | +0·47 | +4 32·2 | −2·0 | 3 | 3 18 55·03 | 31 46 55·9 | *c* |
| 28 | 9 42 27 | | +2 53·33 | +0·50 | +8 16·1 | −1·5 | 3 | 3 22 31·03 | 32 51 28·0 | *d* |
| | 9 42 27 | | +2 14·00 | +0·50 | +0 29·3 | −1·7 | 3 | | | *e* |
| | *Comet c 1887 (Barnard).* | | | | | | | | | |
| Feb. 28 | 12 32 49 | M. | +1 11·25 | −0·10 | +1 56·9 | −3·3 | 2 | | | *f* |
| | 12 39 31 | H. T. | +1 14·65 | −0·10 | +1 54·5 | −3·3 | 2 | | | *g* |
| | *Comet d 1887 (Barnard).* | | | | | | | | | |
| Feb. 28 | 7 44 0 | H. T. | +0 12·20 | +0·33 | +1 25·7 | −9·2 | 6 | | | *h* |

| 1886. | Cape Mean Time. | Comet—Star Δα | Comet—Star Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. $(p \times \Delta)$ | Comet's App. Dec. | Log. $(p \times \Delta)$ | Red. to App. Place. | | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| May 16 | 7 57 54·4 | −0 28·57 | +3 14·1 | 16·12 | F | 7 39 53·61 | 9·7090 | −34 48 34·8 | $0·2723_n$ | −0·16 | −23·6 | 12 |
| 17 | 7 46 35·6 | +0 49·95 | +4 4·5 | 20·16 | F | 7 45 26·57 | 9·6963 | −35 23 33·6 | $0·2063_n$ | −0·14 | −23·7 | 13 |
| 21 | 7 59 48·0 | +0 14·74 | −3 37·4 | 10·8 | F | 8 3 48·69 | 9·7184 | −37 9 43·5 | $0·1981_n$ | −0·08 | −23·8 | 14 |
| 22 | 7 43 14·5 | −1 5·92 | +5 34·0 | 20·16 | F | 8 7 34·73 | 9·7001 | −37 29 43·2 | $0·1080_n$ | −0·05 | −24·1 | 15 |
| 28 | 8 7 31·9 | −1 49·21 | −4 4·0 | 16·12 | F | 8 26 | 9·7436 | −39 | $0·2067_n$ | 0·00 | −23·9 | 16 |
| 29 | 7 53 55·6 | +0 18·28 | −1 14·7 | 20·16 | F | 8 28 53·45 | 9·7308 | −39 13 35·1 | $0·1331_n$ | −0·02 | −23·9 | 17 |
| June 6 | 8 25 16·4 | −1 5·08 | +1 27·1 | 12·12 | F | 8 46 37·21 | 9·7817 | −40 32 24·9 | $0·3180_n$ | −0·01 | −23·2 | 18 |
| 7 | 7 33 27·6 | +0 40·39 | −2 5·2 | 12·12 | F | 8 48 29·15 | 9·7352 | −40 40 40·6 | $0·0545_n$ | −0·01 | −23·2 | 19 |
| 10 | 8 12 3·6 | −0 13·48 | −4 59·7 | 12·12 | F | 8 54 3·37 | 9·7817 | −41 5 28·7 | $0·2862_n$ | −0·01 | −22·9 | 20 |
| 12 | 7 45 11·1 | +0 24·82 | +4 12·3 | 12·12 | F | 8 57 31·58 | 9·7646 | −41 21 12·0 | $0·0713_n$ | −0·01 | −22·7 | 21 |
| 22 | 8 3 40·1 | +0 5·51 | | 20· | F | 9 13 35·71 | 9·8053 | | | −0·02 | −21·6 | 22 |
| | 8 14 42·3 | | +0 3·2 | ·6 | F | | | −42 38 33·0 | $0·3854_n$ | −0·02 | −21·6 | 22 |
| 23 | 8 11 2·5 | −0 49·07 | | 12· | F | 9 15 6·72 | 9·8109 | | | −0·02 | | 23 |
| | 8 11 2·5 | | −1 37·0 | ·16 | F | | | −42 46 16·1 | $0·3857_n$ | −0·02 | −21·5 | 24 |
| 26 | 7 25 41·7 | | −2 21·1 | ·6 | F | | | −43 9 29·2 | $0·1927_n$ | −0·03 | −21·1 | 25 |
| | 7 34 1·0 | +0 25·46 | | 8· | F | 9 19 32·82 | 9·7959 | | | −0·03 | −21·1 | 25 |
| July 3 | 7 29 49·3 | +0 26·80 | −2 40·2 | 10·10 | F | 9 29 28·86 | 9·8117 | −44 6 36·8 | $0·2844_n$ | −0·04 | −20·1 | 26 |
| 5 | 8 4 9·9 | | −0 58·7 | 4 | F | | | −44 23 13·7 | $0·4395_n$ | −0·06 | −19·8 | 27 |
| | 8 13 20·4 | +1 34·23 | | 4 | F | 9 32 31·29 | 9·8337 | | | | | 27 |
| 6 | 7 4 3·0 | −0 26·52 | −1 33·3 | 12·12 | F | 9 33 53·06 | 9·8019 | −44 31 24·7 | $0·1791_n$ | −0·04 | −19·7 | 28 |
| 7 | 7 3 30·5 | | −0 7·0 | ·10 | F | | | −44 39 55·3 | $0·1868_n$ | −0·05 | −19·6 | 29 |

| 1886. | Cape Mean Time. | Comet—star Δα | Comet—star Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. $(p \times \Delta)$ | Comet's App. Dec. | Log. $(p \times \Delta)$ | Red. to App. Place. | | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| July 7 | 7 26 57·8 | +0 11·26 | | 14· | F | 9 35 17·37 | 9·8200 | | | | | 29 |
| 8 | 7 19 20·8 | −0 23·15 | +0 47·0 | 10·12 | F | 9 36 41·40 | 9·8182 | −44 48 44·9 | $0{\cdot}2800_n$ | −0·04 | −19·4 | 30 |
| 20 | 7 26 53·2 | −0 18·26 | −1 10·2 | 12·8 | F | 9 53 11·98 | 9·8495 | −46 39 33·1 | $0{\cdot}4194_n$ | −0·06 | −17·6 | 31 |
| 26 | 7 40 10·0 | −0 51·20 | −0 17·8 | 8·8 | F | 10 1 23·37 | 9·8619 | −47 39 37·4 | $0{\cdot}5069_n$ | −0·06 | −16·6 | 32 |
| 30 | 7 54 42·4 | −0 14·50 | +1 0·2 | 6·4 | F | 10 6 48·28 | 9·8658 | −48 21 29·6 | $0{\cdot}5760_n$ | −0·07 | −15·9 | 33 |

Comet Fabry, May 2, 7h 15m Cape Meantime
(on Argelander's Map.)

Comet Fabry, May 4, 8h 5m Cape Meantime
(on the Berlin Star Maps).

*Notes.*

May 4. Excellent observations: star-like nucleus of 9th magnitude: admits of as easy observation as a star.
5. Observations difficult on account of haze.
12, 13. Good observations: star-like nucleus of 9½ magnitude.
21. Haze constantly blotting out comet.
June 22. Comet faint.
July 5. Comet near a 10½ magnitude star and very faint. Definition exceedingly bad.
6, 8. Very faint: moonlight.
26, 30. Small and faint.

## *Comet* 1886 . . . (*Fabry*).

### *Adopted Mean Places of Comparison Stars.*

| Comp. Star No. | R.A. 1886·0. h m s | Declination 1886·0. ° ′ ″ | Authority. |
|---|---|---|---|
| 1 | 4 5 16·15 | + 5 13 30·5 | Greenwich 7-year and 9-year. |
| 2 | 4 32 50·32 | − 0 37 31·2 | Göttingen, 1263. |
| 3 | 4 55 9·10 | − 6 15 19·1 | 8½ mag. Equat. diff. from *a*. |
| *a* | 4 54 45·61 | − 6 21 44·3 | W.B. iv. 1177. |
| 4 | 5 19 19·68 | −11 5 44·3 | ½ (W.B.V. 407 + Sant. 519). |
| 5 | 5 18 12·46 | −11 18 38·7 | ½ (W.B.V. 382 + Sant. 516). |
| 6 | 5 36 (27) | −15 23 (42) | (=Lal. 10807). |
| 7 | 5 55 54·32 | −19 14 31·5 | 9½ mag. Equat. diff. from *b*. |
| *b* | 6 2 43·92 | −19 9 13·5 | Stone 2801. |
| 8 | 6 54 8·72 | −28 49 3·5 | ε Can. Maj. N.A. |
| 9 | 7 3 21·98 | −30 19 19·8 | Cord. Z. vii. 209. |
| 10 | 7 9 41·45 | −31 26 47·3 | Cord. Z. vii. 626. |
| 11 | 7 20 42·58 | −32 26 37·0 | 8½ mag. Equat. diff. from *c*. |
| *c* | 7 17 49·07 | −32 22 13·3 | Stone 3602. |
| 12 | 7 40 22·34 | −34 51 25·3 | Cord. Z. vii. 2889. |
| 13 | 7 44 36·76 | −35 27 14·4 | 8 mag. Equat. diff. from *d*. |
| *d* | 7 46 7·81 | −35 30 4·8 | Cord. Z. vii. 3384. |
| 14 | 8 3 34·03 | −37 5 42·3 | Cord. Z. viii. 242. |
| 15 | 8 8 40·70 | −37 34 53·1 | Stone 4207. |
| 16 | 8 28 | −38 57 | 9 mag. |
| 17 | 8 28 35·19 | − 39 11 56·5 | Cord. Z. viii. 2355. |
| 18 | 8 47 42·30 | −40 33 28·8 | Stone 4707. |
| 19 | 8 47 48·77 | −40 38 12·2 | C. Z. viii. 3879 and Eq. diff. from 18. |
| 20 | 8 54 16·86 | −41 0 6·1 | 10 mag. Equat. diff. from *e*. |
| *e* | 8 53 20·89 | −40 54 36·2 | Cord. Z. viii. 4288. |
| 21 | 8 57 6·77 | −41 25 1·6 | Stone 4803. |
| 22 | 9 13 30·22 | −42 38 14·6 | 10 mag. Equat. diff. from *f*. |
| *f* | 9 16 29·32 | −42 35 56·1 | Cord. Z. ix. 1284. |
| 23 | 9 15 55·81 | −42 48 49· | dupl. 10 mag. Eq. diff. from 24. |
| 24 | 9 15 8·43 | −42 44 17·6 | Cord. Z. ix. 1175. |
| 25 | 9 19 7·39 | −43 6 47·0 | Cord. Z. ix. 1498. |
| 26 | 9 29 2·10 | −44 3 36·5 | 10 mag. Equat. diff. from *g*. |
| *g* | 9 25 1·44 | −44 2 25·4 | Cord. Z. ix. 1985. |
| 27 | 9 30 57·12 | −44 21 55·2 | 9 mag. Equat. diff. from *h*. |
| *h* | 9 30 22·77 | −44 18 28·9 | Cord. Z. ix. 2418. |
| 28 | 9 34 19·62 | −44 29 31·7 | 9½ mag. diff. from C.Z. ix. 2776. |
| 29 | 9 35 6·16 | −44 39 28·7 | Cord. Z. ix. 2746. |
| 30 | 9 37 4·59 | −44 49 12·5 | 10½ m. diff. from C.Z. ix. 2715. |
| 31 | 9 53 30·30 | −46 38 5·3 | 10½ m. diff. from C.Z. ix. 4184. |
| 32 | 10 2 14·63 | −47 39 3·0 | 10½ m. diff. from C.Z. x. 182. |
| 33 | 10 7 2·85 | −48 22 13·9 | Cord. Z. x. 493. |

## *Observations of Comet* 1886 . . . (*Barnard*).

| 1886. | | Cape Mean Time. | Comet—Star. Δα | Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. ($p \times \Delta$) | Comet's App. Dec. | Log. ($p \times \Delta$) | Red. to App. Place. | | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| May | 29 | 6 1 20·9 | +0 47·59 | −0 27·3 | 8·8 | F | 4 34 29·41 | 9·7095 | −16 57 50·5 | 0·6685$_n$ | −0·71 | − 9·2 | 1 |
| June | 1 | 6 10 6·7 | −1 25·32 | −6 14·7 | 6·4 | F | 5 12 2·46 | 9·7413 | −27 42 52·4 | 0·6059$_n$ | −0·88 | −11·1 | 2 |
| | 5 | 6 37 12·8 | +0 28·98 | −7 57·3 | 4·4 | F | 5 59 37·69 | 9·7890 | −37 40 51·2 | 0·5288$_n$ | −1·04 | −13·8 | 3 |
| | 6 | 6 22 18·8 | −0 11·20 | −2 20·8 | 20·16 | F | 6 10 23·00 | 9·7942 | −39 27 34·5 | 0·4596$_n$ | −1·06 | −14·5 | 4 |
| | 7 | 6 8 34·6 | | −6 16·2 | 6 | F | | | −41 1 2·4 | 0·3609$_n$ | −1·06 | −15·2 | 5 |
| | | 6 23 14·6 | −1 19·88 | | 10 | F | 6 20 46·59 | 9·8008 | | | | | 5 |
| | | 6 35 45·2 | −0 10·94 | | 10 | F | 6 20 52·07 | 9·8058 | | | −1·06 | −15·4 | 6 |
| | | 6 44 44·5 | | +2 39·7 | 6 | F | | | −41 3 14·7 | 0·4818$_n$ | | | 6 |
| | 10 | 6 42 22·7 | +1 29·90 | −3 34·0 | 12·8 | F | | 9·8274 | | 0·3716$_n$ | −1·08 | −16·7 | 7 |
| | | 7 13 50·4 | −0 17·07 | +4 30·7 | 10·8 | F | | 9·8366 | | 0·4833$_n$ | −1·07 | −16·8 | 8 |
| | 12 | 6 55 56·0 | −0 40·77 | −3 21·4 | 20·12 | F | 7 6 10· | 9·8433 | −46 27 34·5 | 0·3656$_n$ | −1·05 | −17·7 | 9 |
| | 15 | 7 31 39·5 | | −2 47·7 | ·4 | F | | | −48 24 58·9 | 0·4405$_n$ | −1·01 | −18·5 | 10 |
| | | 7 41 38·4 | +1 31·32 | | 6· | F | 7 28 32·35 | 9·8677 | | | −1·01 | −18·5 | 10 |
| | 22 | 8 42 40·7 | | +0 42·2 | ·4 | F | | | | 0·6026$_n$ | −0·81 | −20·1 | 11 |
| | | 8 54 54·4 | −4 5·35 | | 4· | F | | 9·8821 | | | | | 11 |
| | 23 | 7 26 39·9 | −0 11·38 | +0 22·2 | 14·12 | F | 8 13 50·68 | 9·8880 | −51 20 42·6 | 0·3162$_n$ | −0·82 | −19·9 | 12 |
| July | 5 | 7 25 17·0 | +1 49·85 | +5 20·4 | 10·8 | F | 8 59 46·66 | 9·9090 | −53 28 39·9 | 0·2781$_n$ | −0·64 | −19·8 | 13 |

| 1886. | Cape Mean Time. | Comet—Star Δα | Comet—Star Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. $(p\times\Delta)$ | Comet's App. Dec. | Log. $(p\times\Delta)$ | Red. to App. Place. | | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| July 6 | 7 58 33·9 | −0 7·63 | +1 13·4 | 19·12 | F | 9 2 58·08 | 9·9169 | −53 36 59·8 | $0·4407_n$ | −0·60 | −19·8 | 14 |
| 7 | 8 0 27·6 | +1 23·23 | +5 14·4 | 10·14 | F | 9 6 0·49 | 9·9184 | −53 44 59·5 | $0·4514_n$ | −0·61 | −19·6 | 15 |
| 8 | 7 58 4·9 | +0 9·01 | −3 53·7 | 9·8 | F | 9 8 59·21 | 9·9197 | −53 52 50·9 | $0·4459_n$ | −0·58 | −19·6 | 16 |
| 20 | 8 2 45·8 | | +5 52·1 | 4 | F | | | −55 24 8·6 | $0·5103_n$ | −0·46 | −18·4 | 17 |
| | 8 18 21·2 | −1 2·46 | | 9 | F | 9 40 9·90 | 9·9317 | | | | | 17 |
| 21 | 6 34 48·6 | | −1 23·3 | 4 | F | | | −55 31 24·0 | $9·9816_n$ | −0·46 | −18·4 | 17 |
| | 6 41 27·1 | +1 7·52 | | 4 | F | 9 42 19·88 | 9·9207 | | | | | 17 |
| 24 | 7 25 50·1 | | −3 4·2 | 4 | F | | | −55 55 2·1 | $0·3768_n$ | −0·44 | −17·8 | 18 |
| | 7 40 6·5 | −0 10·49 | | 12 | F | 9 49 14·04 | 9·9417 | | | | | 18 |
| 26 | 8 20 41·0 | −1 8·03 | −3 1·8 | 6·6 | F | 9 53 44·16 | 9·9363 | −56 11 1·7 | $0·5938_n$ | −0·42 | −17·6 | 19 |

*Notes.*

June 15. Moonlight too strong.

July 5. Faint: very bad definition.

July 6. Faint: moonlight

8. Large, faint and diffused: difficult.

20. Very faint, and so mixed up with two stars that it was almost impossible to fix its position.

21. Cloudy night: observations not of much value.

24. Exceedingly faint: definition very bad.

26. An exceedingly faint and ill-defined patch of light.

### *Comet* 1886 . . . (*Barnard I.*)

#### *Adopted Mean Places of Comparison Stars.*

| Comp. Star No. | R.A. 1886. h m s | Declination 1886. ° ′ ″ | Authority. |
|---|---|---|---|
| 1 | 4 33 42·53 | −16 57 14·0 | Oeltz. Arg. S. 3251. |
| 2 | 5 13 28·66 | −27 36 26·6 | Oeltz. Arg. S. 3846. |
| 3 | 5 59 9·75 | −37 32 40·1 | Stone 2762. |
| 4 | 6 10 35·26 | −39 24 59·2 | 9½ mag. = Stone 2926 { −5ᵐ 27ˢ·23. +1′ 12″·2. |
| 5 | 6 22 7·53 | −40 54 31·0 | Stone 2995. |
| 6 | 6 21 4·07 | −41 5 39·0 | 10 mag. = Stone 3017 { −3ᵐ 5ˢ·00. −1′ 51″·3. |
| 7 | 6 48 (6) | −44 38 | 9 mag. |
| 8 | 6 49 (53) | −44 46 | 9 mag. |
| 9 | 7 6 52· | −46 23 55·4 | 10 mag. = C.Z. vii. 260 { +2ᵐ 53ˢ·28. +2′ 17″·4. |
| 10 | 7 27 2·04 | −48 21 52·7 | Cord. Z. vii. 1876. |
| 11 | 8 13 (9) | −51 6 | 9 mag. |
| 12 | 8 14 2·88 | −51 20 44·9 | 8½ mag. = C.Z. viii. 1471 { −3ᵐ 57ˢ·87. −0′ 44″·6. |
| 13 | 8 57 57·45 | −53 33 40·5 | 10 mag. = C.Z. viii. 4702 { −0ᵐ 22ˢ·17. +5′ 42″·7. |
| 14 | 9 3 6·31 | −53 37 53·4 | C.Z. ix. 229. |
| 15 | 9 4 37·87 | −53 49 54·3 | 8½ mag. = C.Z. ix. 416 { −0ᵐ 36ˢ·60. +4′ 36″·2. |
| 16 | 9 8 50·78 | −53 48 37·6 | C.Z. ix. 666. |
| 17 | 9 41 12·82 | −55 29 42·3 | C.Z. ix. 3183. |
| 18 | 9 49 24·97 | −55 51 40·1 | C.Z. ix. 3790. |
| 19 | 9 54 52·61 | −56 7 42·3 | C.Z. ix. 4203. |

*Comet Brooks I. (1886).*

| 1886. | Cape Mean Time. | Comet – Star. Δα | Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. $(p \times \Delta)$ | Comet's App. Decl. | Log. $(p \times \Delta)$ | Red. to App. Place. | | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| July 5 | 6 31 14·3 | −1 22·96 | +3 30·5 | 6·4 | F | | 9·6810 | | 0·6589$_n$ | −0·03 | −11·6 | 1 |
| 6 | 6 18 46·5 | −0 27·10 | +3 53·1 | 16·16 | F | 8 30 41·86 | 9·6735 | − 9 15 26·1 | 0·6512$_n$ | −0·01 | −11·6 | 2 |
| 7 | 6 26 17·1 | +0 31·60 | −2 3·6 | 20·16 | F | 8 36 56·66 | 9·6768 | − 9 29 57·7 | 0·6523$_n$ | 0·00 | −11·5 | 3 |
| 8 | 6 33 31·7 | +1 3·55 | +1 17·6 | 16·12 | F | | 9·6799 | | 0·6537$_n$ | +0·02 | −11·5 | 4 |
| 9 | 6 30 55·9 | +0 1·33 | +0 27·2 | 30·16 | F | | 9·6774 | | 0·6501$_n$ | +0·04 | −11·5 | 5 |
| 12 | 6 48 53·1 | −2 29·03 | −7 29·3 | 4·4 | F | 9 5 15·51 | 9·6853 | −10 27 24·8 | 0·6552$_n$ | +0·10 | −11·4 | 6 |
| 14 | 6 32 30·5 | +1 3·07 | −2 6·4 | 10·8 | F | 9 15 17·89 | 9·6755 | −10 44 58·6 | 0·6432$_n$ | +0·13 | −11·2 | 7 |
| | 6 32 30·5 | −0 46·02 | +0 7·7 | 10·8 | F | | 9·6755 | | 0·6432$_n$ | +0·13 | −11·2 | 8 |
| 20 | 6 39 1·1 | +0 54·38 | −1 32·0 | 16·10 | F | 9 42 9·29 | 9·6789 | −11 26 23·8 | 0·6417$_n$ | +0·22 | −10·7 | 9 |
| | 6 39 1·1 | −0 38·05 | +1 14·2 | 16·10 | F | 9 42 9·21 | 9·6789 | −11 26 29·0 | 0·6417$_n$ | +0·22 | −10·7 | 10 |
| 24 | 6 49 10·1 | +0 33·75 | −2 5·2 | 14·8 | F | 9 57 40·53 | 9·6849 | −11 47 27·4 | 0·6461$_n$ | +0·27 | −10·3 | 11 |
| 26 | 6 41 26·3 | +1 45·79 | +1 16·3 | 10·8 | F | 10 4 47·09 | 9·6815 | −11 56 33·8 | 0·6409$_n$ | +0·29 | −10·1 | 12 |
| 28 | 6 37 15·7 | −0 52·36 | +1 4·0 | 8·6 | F | 10 11 33·04 | 9·6800 | −12 5 7·5 | 0·6382$_n$ | +0·32 | − 9·8 | 13 |
| 29 | 6 41 55·1 | +0 19·19 | −1 23·9 | 10·8 | F | 10 14 50·26 | 9·6829 | −12 9 8·9 | 0·6411$_n$ | +0·33 | − 9·7 | 14 |
| 30 | 6 46 25·4 | −1 49·76 | −1 57·1 | 8·8 | F | 10 18 2·49 | 9·6861 | −12 13 12·5 | 0·6446$_n$ | +0·35 | − 9·6 | 15 |

*Notes.*

July 5. A bright circular mass, about ¾′ in diameter, gradually condensed toward the centre.

12. Hazy sky: observations rough.

14. Comet very faint: bright moonlight.

20. A diffused mass without any particular condensation.

24. Definition bad. A rather faint diffused patch of light: does not admit of very accurate observation.

29. Faint and ill-defined; a difficult object to observe.

30. Very faint.

*Comet* 1886 . . . (*Brooks I.*).

*Adopted Mean Places of Comparison Stars.*

| Comp. Star No. | R.A. 1886·0. h m s | Declination 1886·0. ° ′ ″ | Authority. |
|---|---|---|---|
| 1 | 8 25 (42) | − 9 3 | 8 mag. |
| 2 | 8 31 8·97 | − 9 19 7·6 | Yarnall 3507. |
| 3 | 8 36 25·06 | − 9 27 42·6 | 9 mag. Equat. diff. from *a*. |
| *a* | 8 37 23·63 | − 9 23 49·5 | W.B. viii. 942. |
| 4 | 8 41 (48) | − 9 44 | 10½ mag. = *b* { + 1$^m$ 27$^s$·40. + 5′ 20″·9. |
| *b* | 8 40 (21) | − 9 49 | 9 mag. |
| 5 | 8 49 (7) | − 9 57 | 10½ mag. = *c* { − 2$^m$ 25$^s$·30. − 1′ 49″·4. |
| *c* | 8 51 (32) | − 9 55 | 9 mag. |
| 6 | 9 7 44·44 | −10 19 44·1 | Santini 1142. |
| 7 | 9 14 14·69 | −10 42 41·0 | Santini 1155. |
| 8 | 9 16 (3) | −10 45 | 9 mag. |
| 9 | 9 41 14·69 | −11 24 41·1 | ½ (Yarnall + Santini). |
| 10 | 9 42 47·04 | −11 27 32·5 | Santini 1199. |
| 11 | 9 57 6·51 | −11 45 11·9 | 10½ mag. diff. from *d*. |
| *d* | 10 0 40·92 | −11 51 37·6 | 9½ mag. diff. from *e*. |
| *e* | 10 1 6·25 | −11 55 5·1 | W.B. ix. 1277. |
| 12 | 10 3 1·01 | −11 57 40·0 | ½ (Schj. + diff. from λ Hydræ). |
| 13 | 10 12 25·08 | −12 6 1·7 | 9½ mag. diff. from W.B. X. 114 and X. 204. |
| 14 | 10 14 30·74 | −12 7 35·3 | 10 mag. diff. from ∗ 13 and Lam. 711. |
| 15 | 10 19 51·90 | −12 11 5·8 | Lamont Z. 711. |

*Winnecke's Comet.*

| 1886. | Cape Mean Time. h m s | Comet − Star. Δα m s | Comet − Star. Δδ ′ ″ | No. of Comps. | Observer. | Comet's App. R.A. h m s | Log. (p×Δ) | Comet's App. Decl. ° ′ ″ | Log. (p×Δ) | Red. to App. Place. s | Red. to App. Place. ″ | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug. 19 | 8 12 28·8 | −0 44·77 | −3 5·7 | 3·5 | F | 13 7 6·07 | 9·674 | − 0 34 2·8 | 0·690$_n$ | +0·83 | − 0·9 | 1 |
| 20 | 7 1 49·9 | +0 50·87 | +0 17·1 | 16·12 | F | 13 10 21·47 | 9·613 | − 1 8 17·8 | 0·684$_n$ | +0·84 | − 1·0 | 2 |
| 20 | 7 39 2·0 | −1 10·10 | −4 16·3 | 10·8 | F | 13 10 26·82 | 9·651 | − 1 9 14·0 | 0·686$_n$ | +0·85 | − 0·9 | 3 |
| 21 | 7 12 7·4 | +1 37·91 | −0 26·1 | 12·12 | F | 13 13 50·77 | 9·626 | − 1 45 1·9 | 0·681$_n$ | +0·85 | − 1·0 | 4 |
| 22 | 6 47 5·3 | +0 13·99 | −1 21·0 | 12·12 | F | 13 17 | 9·595 | − 2 21 | 0·675$_n$ | +0·87 | − 0·9 | 5 |
| 25 | 7 35 35·4 | −1 18·82 | +4 56·2 | 11·8 | F | 13 28 11·92 | 9·651 | − 4 16 3·0 | 0·670$_n$ | +0·92 | − 0·7 | 6 |
| 29 | 7 28 34·7 | +0 27·69 | +3 0·5 | 12·12 | F | 13 43 9·99 | 9·648 | − 6 53 12·4 | 0·653$_n$ | +0·98 | − 0·6 | 7 |
| Sept. 4 | 7 34 15·1 | −0 35·33 | +4 31·4 | 12·12 | F | 14 7 9·98 | 9·658 | −11 1 3·0 | 0·627$_n$ | +1·02 | − 0·9 | 8 |
| 16 | 7 43 5·3 | | +5 6·4 | 0·4 | F | | | −19 41 47·4 | 0·558$_n$ | +1·27 | + 0·2 | 9 |
| 16 | 7 49 59·2 | +1 2·77 | | 3·0 | F | 15 1 51·61 | 9·682 | | | +1·27 | + 0·2 | 9 |
| 17 | 7 38 19·5 | −1 42·06 | −0 16·1 | 16·12 | F | 15 6 50·35 | 9·674 | −20 25 11·6 | 0·544$_n$ | +1·31 | + 0·4 | 10 |
| 18 | 7 36 44·7 | +0 46·16 | +0 32·6 | 16·12 | F | 15 11 56·35 | 9·673 | −21 8 34·7 | 0·533$_n$ | +1·31 | + 0·3 | 11 |
| 19 | 7 31 29·1 | −0 9·45 | +5 4·4 | 8·8 | F | 15 17 7·49 | 9·669 | −21 51 35·9 | 0·516$_n$ | +1·34 | + 0·4 | 12 |
| 20 | 7 25 58·0 | −0 1·36 | −2 15·4 | 26·12 | F | 15 22 22·77 | 9·664 | −22 34 19·7 | 0·498$_n$ | +1·36 | + 0·5 | 13 |
| 25 | 7 52 47·7 | −1 50·32 | −2 18·1 | 16·12 | F | 15 50 12·10 | 9·695 | −26 3 16·4 | 0·485$_n$ | +1·47 | + 1·0 | 14 |
| 26 | 7 40 27·8 | −0 51·32 | −2 14·9 | 16·12 | F | 15 55 58·06 | 9·684 | −26 42 54·9 | 0·450$_n$ | +1·49 | + 1·1 | 15 |
| 27 | 9 9 22·4 | +1 5·14 | +0 53·6 | 10·8 | F | 16 2 14·06 | 9·739 | −27 24 32·6 | 0·598$_n$ | +1·51 | + 1·1 | 16 |
| 30 | 8 50 22·4 | +0 12·83 | −4 23·5 | 16·12 | F | 16 20 24·50 | 9·738 | −29 16 36·0 | 0·541$_n$ | +1·57 | + 1·5 | 17 |
| Oct. 1 | 8 32 3·4 | | −3 19·3 | 0·4 | F | | | −29 51 48·8 | 0·494$_n$ | +1·59 | + 1·6 | 18 |
| 1 | 8 41 7·9 | +1 43·80 | | 3·0 | F | 16 26 37·56 | 9·735 | | | +1·59 | + 1·6 | 18 |
| 15 | [illegible] | | | [illegible] | F | [illegible] 2·38 | 9·718 | −35 54 33·6 | 0·257$_n$ | +1·88 | + 4·0 | 19 |

| 1886. | Cape Mean Time. | Comet—Star Δα | Comet—Star Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. (p×Δ) | Comet's App. Dec. | Log. (p×Δ) | Red. to App. Place. | | Comp. Star No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| Oct. 18 | 8 28 25·2 | −0 16·10 | +1 24·7 | 16·12 | F | | 9·717 | | 0·225n | +1·91 | + 4·5 | 20 |
| 19 | 8 39 2·7 | −0 29·02 | +4 10·5 | 16·12 | F | 18 29 8·26 | 9·727 | −36 42 44·7 | 0·253n | +1·94 | + 4·8 | 21 |
| 21 | 9 8 57·4 | +0 20·18 | −0 37·7 | 16·12 | F | 18 43 10·21 | 9·751 | −36 57 8·9 | 0·337n | +1·95 | + 5·2 | 22 |
| 22 | 8 14 23·9 | +1 18·95 | −0 46·1 | 12·12 | F | 18 49 48·25 | 9·686 | −37 1 48·8 | 0·084n | +1·96 | + 5·4 | 23 |
| 29 | 9 1 40·3 | | −0 43·0 | 0·4 | F | 19 36 37 | | −36 54 20·0 | 0·220n | +2·01 | + 6·7 | 24 |
| 31 | 8 30 21·6 | | +0 5·7 | 0·4 | F | | | | 0·049n | +2·03 | + 7·1 | 25 |
| 31 | 8 41 4·9 | −0 18·65 | | 6·0 | F | | 9·688 | | | +2·03 | + 7·1 | 25 |
| Nov. 2 | 8 12 45·7 | −1 11·85 | −0 25·4 | 10·8 | F | 20 1 13·60 | 9·633 | −36 22 14·9 | 9·938n | +2·03 | + 7·5 | 26 |
| 13 | 8 1 12·3 | | +2 37·9 | 0·4 | F | | | | 9·935n | +2·04 | + 9·0 | 27 |
| 13 | 8 11 32·1 | −0 26·34 | | 12·0 | F | | 9·581 | | | +2·04 | + 9·0 | 27 |
| 17 | 9 15 15·6 | | +2 36·4 | 0·4 | F | | | −32 23 3·5 | 0·283n | +2·04 | + 9·5 | 28 |
| 17 | 9 23 36·6 | +0 23·17 | | 10·0 | F | 21 10 35·42 | 9·690 | | | +2·04 | + 9·5 | 28 |
| 19 | 9 42 58·4 | +1 46·70 | −0 7·8 | 5·5 | F | 21 29 33·74 | 9·707 | −31 42 30·0 | 0·375n | +2·03 | + 9·6 | 29 |
| 23 | 8 37 8·6 | +0 32·88 | −0 51·7 | 8·8 | F | 21 46 9·33 | 9·607 | −30 21 47·3 | 0·212n | +2·05 | +10·0 | 30 |
| 25 | 8 55 16·9 | +1 9·11 | −1 8·1 | 8·10 | F | 21 54 7·76 | 9·635 | −29 36 59·8 | 0·287n | +2·03 | +10·1 | 31 |
| 26 | 9 21 36·0 | −1 41·73 | +0 10·3 | 10·8 | F | 21 58 3·11 | 9·671 | −29 15 12·2 | 0·363n | +2·04 | +10·1 | 32 |
| 29 | 9 9 15·4 | +0 48·73 | +5 39·9 | 10·8 | F | 22 9 7·47 | 9·651 | −28 10 23·9 | 0·357n | +2·03 | +10·1 | 33 |

*Notes.*

Aug. 25. Observations made through cloud: not very good.
Sept. 16. Comet seen during a short break in the clouds.
Oct. 1. Moonlight and clouds; observations not very valuable.
Nov. 2. Faint in the moonlight.

Sept. 4. Bright moonlight: comet faint.
18. Well condensed towards centre, but scarcely a stellar nucleus.
Oct. 29. Clouds prevented further observations.
Nov. 17. Faint from this date onwards.

## *Winnecke.*

### *Adopted Mean Places of Comparison Stars.*

| Comp. Star No. | R.A. 1886·0. | Declination 1886·0. | Authority. |
|---|---|---|---|
| | h m s | ° ′ ″ | |
| 1 | 13 7 50·01 | − 0 30 56·2 | 10 mag. Equat. diff. from ✱ *a*. |
| *a* | 13 13 7·91 | − 0 40 3·1 | Copeland and Börgen 3986. |
| 2 | 13 9 29·76 | − 1 8 33·9 | Copeland and Börgen 3979. |
| 3 | 13 11 36·07 | − 1 4 56·8 | Copeland and Börgen 3982. |
| 4 | 13 12 12·01 | − 1 44 34·8 | 9 mag. one Equat. diff. from ✱ *b*. |
| *b* | 13 18 31·41 | − 1 42 54·3 | Copeland and Börgen 3996. |
| 5 | 13 16 (58) | − 2 20 | 10 mag. |
| 6 | 13 29 29·82 | − 4 20 58·5 | W.B. xiii. 465. |
| 7 | 13 42 41·32 | − 6 56 12·3 | 10½ mag. Equat. diff. from ✱ *c*. |
| *c* | 13 44 33·32 | − 7 1 50·7 | Schjel. 4937–8. |
| 8 | 14 7 44·29 | −11 5 33·5 | 10 mag. Equat. diff. from ✱ *d*. |
| *d* | 14 4 34·19 | −11 5 55·9 | W.B. xiv. 33. |
| 9 | 15 0 47·57 | −19 46 54·0 | Oeltz. Arg. S. 14264–5. |
| 10 | 15 8 31·10 | −20 24 55·9 | 9½ mag. Equat. diff. from ✱ *e*. |
| *e* | 15 9 13·15 | −20 30 50·7 | Oeltz. Arg. S. 14402. |
| 11 | 15 11 8·88 | −21 9 7·6 | Wash. Zones 255–18. |
| 12 | 15 17 15·60 | −21 56 40·7 | 9 mag. Equat. diff. from ✱ *f*. |
| *f* | 15 14 56·45 | −21 55 55·1 | Oeltz. Arg. S. 14484. |
| 13 | 15 22 22·77 | −22 32 4·8 | 9½ mag. Equat. diff. from ✱ *g*. |
| *g* | 15 20 30·67 | −22 29 23·1 | Oeltz. Arg. S. 14561. |
| 14 | 15 52 0·95 | −26 0 59·3 | 9 mag. Equat. diff. from ✱ *h*. |
| *h* | 15 48 36·85 | −25 55 43·6 | Stone 8647. |
| 15 | 15 56 47·89 | −26 40 41·1 | ½ (C.Z. 3944 + Eq. diff. C.Z. 4023). |
| 16 | 16 1 7·41 | −27 25 27·3 | C.Z. xvi. 30. |
| 17 | 16 20 10·10 | −29 12 14·0 | ½ (C.Z. 1357 + Eq. diff. C.Z. 1559). |
| 18 | 16 24 52·17 | −29 48 31·1 | ½ (C.Z. 1653 + Eq. diff. C.Z. 1592). |
| 19 | 18 1 39·62 | −35 56 22·6 | 9½ mag. Equat. diff. from ✱ *k*. |
| *k* | 17 58 41·47 | −36 1 36·7 | ½ (Stone 9855 + C.Z. 3937). |

| Comp. Star No. | R.A. 1886·0. | Declination 1886·0. | Authority. |
|---|---|---|---|
| | h m s | ° ′ ″ | |
| 20 | 18 22 (13) | −36 35 | 9½ mag. = ✱ *l* $\begin{cases} +2^{m}\ 16^{s}{\cdot}00. \\ -1'\ 28''{\cdot}7. \end{cases}$ |
| *l* | 18 19 (57) | −36 33 | 9 mag. |
| 21 | 18 29 35·34 | −36 47 0·0 | 9½ mag. Equat. diff. from ✱ *m*. |
| *m* | 18 36 25·26 | −36 49 39·5 | Stone 10182. |
| 22 | 18 42 48·08 | −36 56 36·4 | C.Z. xviii. 2375. |
| 23 | 18 48 27·34 | −37 1 8·1 | C.Z. xviii. 2633. |
| 24 | 19 34 39·04 | −36 53 43·7 | ½(C.Z. 1443 + Stone 10615). |
| 25 | 19 49 (28) | −36 40 | 9½ mag. |
| 26 | 20 2 23·42 | −36 21 57·0 | 9½ mag. Equat. diff. from ✱ *n*. |
| *n* | 20 3 42·19 | −36 23 12·4 | Stone 10813. |
| 27 | 21 2 (0) | −33 45 | 9½ mag. = ✱ *o* $\begin{cases} -0^{m}\ 37^{s}{\cdot}50. \\ -4'\ 42''{\cdot}2. \end{cases}$ |
| *o* | 21 2 (38) | −33 40 | 9½ mag. |
| 28 | 21 10 10·21 | −32 25 49·4 | C.Z. xxi. 608. |
| 29 | 21 27 45·01 | −31 42 31·8 | 9½ mag. one Equat. diff. from ✱ *p*. |
| *p* | 21 35 15·81 | −31 46 43·8 | C.Z. xxi. 1065. |
| 30 | 21 45 34·40 | −30 21 5·6 | 10 mag. Equat. diff. from ✱ *q*. |
| *q* | 21 43 59·27 | −30 16 40·5 | C.Z. xxi. 1353. |
| 31 | 21 52 56·62 | −29 36 1·8 | ½(C.Z. 1644 + Stone 11567). |
| 32 | 21 59 42·80 | −29 15 32·6 | C.Z. xxi. 1870. |
| 33 | 22 8 16·71 | −28 16 13·9 | ½(C.Z. 232 + Eq. diff. Stone 11657). |

*Comet* 1886 *e* . . . (*Finlay*).

| 1886. | Cape Mean Time. | Comet – Star. Δα | Comet – Star. Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. (p×Δ) | Comet's App. Decl. | Log. (p×Δ) | Red. to App. Place. | | Star of Comp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| Sept. 26 | 9 14 40·8 | −1 29·21 | +1 38·1 | 14·12 | F | 17 2 1·78 | 9·7046 | −26 4 10·5 | 0·5069ₙ | +1·82 | + 4·2 | 1 |
| 27 | 8 28 10·1 | +0 49·66 | −1 19·9 | 12·10 | F | 17 4 20·63 | 9·6628 | −26 7 8·4 | 0·4266ₙ | +1·80 | + 4·3 | 1 |
| 27 | 9 38 24·5 | +0 56·56 | −1 26·5 | 8·8 | F | 17 4 27·53 | 9·7220 | −26 7 15·0 | 0·5528ₙ | +1·80 | + 4·3 | 1 |
| 29 | 9 19 7·7 | +1 55·16 | −2 29·0 | 6·6 | F | 17 9 19·54 | 9·7129 | −26 13 4·9 | 0·5247ₙ | +1·78 | + 4·5 | 2 |
| 30 | 7 56 12·6 | +0 25·06 | −4 25·7 | 24·16 | F | 17 11 42·50 | 9·6253 | −26 15 46·0 | 0·3690ₙ | +1·78 | + 4·7 | 3 |
| Oct. 1 | 7 53 16·0 | −0 5·93 | +0 32·4 | 6·6 | F | 17 14 15·87 | 9·6231 | −26 18 30·4 | 0·3647ₙ | +1·78 | + 4·8 | 4 |
| 2 | 7 30 48·6 | | +1 54·2 | 0·4 | F | | | −26 21 5·1 | 0·3212ₙ | +1·76 | + 4·8 | 5 |
| 2 | 8 2 19·4 | +2 31·03 | | 15·0 | F | 17 16 53·96 | 9·6389 | | | +1·76 | + 4·8 | 5 |
| 5 | 7 57 55·6 | +2 3·21 | +2 5·4 | 10·8 | F | 17 24 59·05 | 9·6383 | −26 28 1·4 | 0·3816ₙ | +1·75 | + 5·2 | 6 |
| 10 | 7 43 26·3 | +0 46·50 | −0 25·3 | 4·4 | F | 17 39 22·17 | 9·6246 | −26 36 19·3 | 0·3597ₙ | +1·74 | + 6·0 | 7 |
| 15 | 7 39 44·4 | +0 13·67 | −2 11·6 | 16·12 | F | | 9·6260 | | 0·3594ₙ | +1·72 | + 6·7 | 8 |
| 18 | 7 42 50·8 | +0 36·83 | +1 42·1 | 20·12 | F | 18 4 48·96 | 9·6337 | −26 38 6·7 | 0·3711ₙ | +1·71 | + 7·2 | 9 |
| 19 | 7 42 36·9 | −0 57·66 | +0 25·7 | 16·12 | F | | 9·6339 | | 0·3715ₙ | +1·72 | + 7·4 | 10 |
| 21 | 8 0 49·3 | −1 54·99 | −4 3·8 | 16·12 | F | 18 15 10·78 | 9·6600 | −26 34 12·9 | 0·4119ₙ | +1·72 | + 7·7 | 11 |
| 21 | 8 0 49·3 | −2 24·65 | −1 16·4 | 16·12 | F | 18 15 10·78 | 9·6600 | −26 34 12·0 | 0·4119ₙ | +1·72 | + 7·7 | 12 |
| 22 | 8 15 25·9 | +1 9·33 | +0 45·1 | 23·12 | F | 18 18 44·74 | 9·6774 | −26 32 10·4 | 0·4422ₙ | +1·70 | + 7·8 | 12 |
| 26 | 7 52 23·1 | −1 28·60 | +3 14·9 | 10·8 | F | 18 33 17·51 | 9·6504 | −26 20 39·8 | 0·4022ₙ | +1·71 | + 8·4 | 13 |
| 29 | 7 46 36·0 | | +1 0·7 | 0·4 | F | | | −26 7 46·9 | 0·3958ₙ | +1·70 | + 8·8 | 14 |
| 29 | 8 3 15·6 | +0 34·82 | | 10·0 | F | 18 44 44·74 | 9·6645 | | | +1·70 | + 8·8 | 14 |
| 30 | 7 42 52·9 | | +1 55·0 | 0·6 | F | | | −26 2 40·7 | 0·3885 | +1·70 | + 9·0 | 15 |
| 30 | 8 3 19·9 | −0 7·99 | | 14·0 | F | 18 48 38·33 | 9·6634 | | | +1·70 | + 9·0 | 15 |
| Nov. 13 | 8 40 3·9 | −0 9·42 | +1 39·4 | 12·8 | F | 19 47 59·29 | 9·6967 | −23 55 0·5 | 0·5288ₙ | +1·71 | +11·2 | 16 |

| 1886. | Cape Mean Time. | Comet—Star. Δα | Comet—Star. Δδ | No. of Comps. | Observer. | Comet's App. R.A. | Log. (p×Δ) | Comet's App. Dec. | Log. (p×Δ) | Red. to App. Place. | | Star of Comp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | | h m s | | ° ′ ″ | | s | ″ | |
| Nov. 17 | 8 25 22·9 | +0 50·63 | −0 10·5 | 11·8 | F | 20 6 16·29 | 9·6701 | −22 56 54·4 | 0·4994n | +1·70 | +11·7 | 17 |
| 19 | 8 8 4·2 | +0 32·73 | −2 19·5 | 16·12 | F | 20 15 36·22 | 9·6471 | −22 23 45·8 | 0·4787n | +1·72 | +12·1 | 18 |
| 22 | 8 14 26·6 | −0 45·30 | +1 3·1 | 24·12 | F | 20 29 57·16 | 9·6490 | −21 28 47·5 | 0·4965n | +1·74 | +12·6 | 19 |
| 23 | 8 7 41·4 | −0 11·38 | +3 38·9 | 20·12 | F | 20 34 46·43 | 9·6386 | −21 9 13·2 | 0·4905n | +1·74 | +12·7 | 20 |
| 25 | 8 9 12·6 | −0 28·86 | −2 12·4 | 16·12 | F | 20 44 33·66 | 9·6360 | −20 27 14·1 | 0·4996n | +1·76 | +13·0 | 21 |
| 26 | 8 8 58·8 | −0 20·75 | −4 40·3 | 16·12 | F | 20 49 28·77 | 9·6335 | −20 5 15·9 | 0·5030n | +1·74 | +13·0 | 22 |
| 29 | 8 12 24·6 | +0 26·75 | +0 19·7 | 16·12 | F | 21 4 24·98 | 9·6308 | −18 54 39·2 | 0·5182n | +1·78 | +13·4 | 23 |
| Dec. 4 | 8 30 36·8 | | +3 34·0 | 0·8 | F | | | −16 42 39·4 | 0·5569n | +1·81 | +14·0 | 24 |
| 6 | 8 50 4·2 | +0 7·71 | +1 18·1 | 20·12 | F | 21 40 | 9·6568 | −15 47 | 0·5821n | +1·84 | +14·3 | 25 |
| 13 | 8 34 48·4 | −1 31·33 | +0 48·2 | 12·8 | F | 22 16 7·41 | 9·6235 | −12 3 42·7 | 0·5987n | +1·92 | +14·9 | 26 |
| 15 | 8 36 46·0 | −1 18·35 | +0 38·1 | 22·12 | F | 22 26 27·86 | 9·6217 | −10 55 42·1 | 0·6091n | +1·97 | +15·0 | 27 |
| 16 | 8 27 23·6 | −0 25·81 | +3 59·0 | 12·8 | F | 22 31 36·10 | 9·6067 | −10 21 13·5 | 0·6086n | +1·98 | +15·1 | 28 |
| 17 | 8 30 20·5 | −0 16·05 | −1 24·1 | 18·12 | F | 22 36 46·97 | 9·6086 | − 9 46 7·6 | 0·6150n | +2·00 | +15·2 | 29 |
| 18 | 8 34 51·6 | −0 26·72 | +0 19·4 | 18·12 | F | 22 41 56·86 | 9·6121 | − 9 10 38·5 | 0·6219n | +2·01 | +15·2 | 30 |
| 23 | 8 46 45·6 | −1 53·18 | +0 6·3 | 14·12 | F | 23 7 38·95 | 9·6163 | − 6 9 9·3 | 0·6490n | +2·11 | +15·4 | 31 |
| 27 | 8 50 22·1 | +0 50·44 | −2 45·6 | 16·12 | F | 23 27 56·42 | 9·6138 | − 3 41 14·2 | 0·6668n | +2·18 | +15·5 | 32 |
| 28 | 8 47 1·9 | −0 27·83 | −0 24·6 | 16·12 | F | 23 32 (56) | 9·6080 | − 3 5 | 0·6706n | +2·21 | +15·4 | 33 |

*Notes.*

Sept. 26. Faint, round, very slightly more condensed towards the centre.

27. The second set of observations is the better: during the first set the comet was approaching a star, 11 mag., which completely overpowered it at last.

Oct. 1. Hazy night: comet close enough to the comparison star to be rendered rather difficult.

5, 10. Moonlight. Oct. 26. Hazy.

Nov. 25. Strong S.E. wind: the central condensation seemed somewhat elongated in position-angle 165° ±, but the definition was very bad this night.

29. Very bad definition: strong wind. Dec. 4. Chronograph failed: signals not recorded.

*Comet* 1886 *e* . . . (*Finlay*).

*Adopted Mean Places of Comparison Stars.*

| Comp. Star No. | R.A. 1886·0. h m s | Declination 1886·0. ° ′ ″ | Authority. |
|---|---|---|---|
| 1 | 17 3 29·17 | −26 5 52·8 | = A.O. 16394 comp. with C.Z. 373, 550. |
| 2 | 17 7 22·60 | −26 10 40·4 | 9½ mag. Equat. diff. from ✱ 1. |
| 3 | 17 11 15·66 | −26 11 25·0 | ½ (C.Z. 728 + Equat. diff. from C.Z. 934). |
| 4 | 17 14 20·02 | −26 19 7·6 | C.Z. xvii. 927. |
| 5 | 17 14 21·17 | −26 23 4·1 | C.Z. xvii. 928. |
| 6 | 17 22 54·09 | −27 30 12·0 | 9½ mag. = C.Z. 1430 { +1ᵐ 10ˢ·36. +7′ 43″·4. |
| 7 | 17 38 33·93 | −26 36 0·0 | 9½ mag. = A.O. 17142 { +0ᵐ 51ˢ·30. −3′ 52″·3. |
| 8 | 17 54 (37) | −26 38 | 9½ mag. = ✱ *a* { −3ᵐ 37ˢ·05. +0′ 46″·9. |
| *a* | 17 58 (14) | −26 39 | 9 mag. |
| 9 | 18 4 10·42 | −26 39 56·0 | Wash. Zones 100–56 and 36–93. |
| 10 | 18 9 (10) | −26 37 | 10 mag. = ✱ *b* { −0ᵐ 59ˢ·90. −1 9″·3. |
| *b* | 18 10 (10) | −26 36 | 9 mag. |
| 11 | 18 17 4·05 | −26 30 16·8 | ½ (C.Z. 1037 + Yarnall). |
| 12 | 18 17 33·71 | −26 33 3·3 | ½ (C.Z. 1071 + Yarnall). |
| 13 | 18 34 44·40 | −26 24 3·1 | 9½ mag. = C.Z. 1732 { +5ᵐ 0ˢ·70. −1′ 15″·4. |
| 14 | 18 44 8·22 | −26 8 56·4 | C.Z. xviii. 2438. |
| 15 | 18 48 44·62 | −26 4 44·7 | Wash. Zones 127–24. |
| 16 | 19 48 7·00 | −23 56 51·1 | 9½ mag. = C.Z. xix. 2002 { −0ᵐ 36ˢ·90. +3′ 38″·6. |
| 17 | 20 5 23·96 | −22 56 55·6 | 9½ mag. = A.O. 20264 { +3ᵐ 19ˢ·75. +4′ 25″·2. |
| 18 | 20 15 1·77 | −22 21 38·4 | 9½ mag. = A.O. 20436 { −0ᵐ 23ˢ·60. −2′ 44″·6. |
| 19 | 20 30 40·72 | −21 30 3·2 | 9½ mag. = ✱ *c* { −1ᵐ 7ˢ·75. −6′ 41″·1. |
| *c* | 20 31 48·47 | −21 23 22·1 | ½ (A.O. 20678 + Wash. 1860). |
| 20 | 20 34 56·07 | −21 13 4·8 | (= A.O. 20744) Wash Zones (2 obs.). |
| 21 | 20 45 0·76 | −20 25 14·7 | 10½ mag. Equat. diff. from ✱ *d*. |
| *d* | 20 40 6·16 | −20 26 45·7 | 9¼ mag. Wash. Zones 190. |
| 22 | 20 49 47·78 | −20 0 48·6 | 9½ mag. Equat. diff. from ✱ *e*. |
| *e* | 20 45 44·88 | −20 4 12·8 | Radcliffe Obs. 1881. |
| 23 | 21 3 56·45 | −18 55 12·3 | A.O. 21180. |
| 24 | 21 28 55·51 | −16 46 27·4 | 9 mag. Equat. diff. from ✱ *f*. |
| *f* | 21 27 22·21 | −16 42 15·7 | (= A.O. 21468) Edinburgh Catalogue. |
| 25 | 21 39 (59) | −15 48 | 9½ mag. = ✱ *g* { −2ᵐ 26ˢ·45. +1′ 31″·3. |
| *g* | 21 42 (25) | −15 50 | 9 mag. |
| 6 | 22 17 36·82 | −12 4 45·8 | 10 mag. Equat. diff. from ✱ *h*. |
| *h* | 22 12 50·80 | −12 7 38·7 | ½ (Schj. 9115 + Sant. 2507). |
| 27 | 22 27 44·24 | −10 56 35·2 | 9½ mag. Equat. diff. from ✱ *k*. |

| Comp. Star No. | R.A. 1886·0. h m s | Declination 1886·0. ° ′ ″ | Authority. |
|---|---|---|---|
| *k* | 22 31 13·30 | −10 51 39·1 | ½ (Yarnall 9932 + Sant. 2550). |
| 28 | 22 31 59·93 | −10 25 27·6 | 9½ mag. 1 Equat. diff. from * *l*. |
| *l* | 22 36 30·73 | −10 30 50·7 | (= Lal. 44394–5) Paris Obs. 1862. |
| 29 | 22 37 1·02 | − 9 44 58·7 | ½ (Schj + Santini). |
| 30 | 22 42 21·57 | − 9 11 13·1 | 9½ mag. Equat. diff. from * *m*. |
| *m* | 22 45 48·20 | − 9 9 45·1 | Schjellerup 9365. |
| 31 | 23 9 30·02 | − 6 9 31·0 | 10 mag. Equat. Diff. from * *n*. |
| *n* | 23 12 2·17 | − 6 8 22·5 | 9 mag. Astr. Nach. lxxxvi. p. 215. |
| 32 | 23 27 3·80 | − 3 38 44·1 | Karlsruhe Zones (Valentiner). |
| 33 | 23 33 (22) | − 3 5 | 9½ mag. |

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## *Observations of Winnecke's Comet,* 1886, *made at Windsor, New South Wales.* By John Tebbutt.

Notice of the discovery of this comet at the Cape of Good Hope was received here on August 25. The comet was found on the same evening, and observations of it continued as long as possible. As it was at no time bright enough to admit of observation in an illuminated field, and there were no means of illuminating the threads of the filar micrometer on a dark field, I was obliged to have recourse to a dark field micrometer. Of the accompanying positions those for August were determined with a square bar-micrometer on the Cooke 4½-inch Equatorial. On Sept. 1 a ring-micrometer, whose mean radius = 242″·6, was fitted to the recently mounted Grubb 8-inch Equatorial, and with this instrument observations were continued till Sept. 18, when the square bar-micrometer hitherto employed with the 4½-inch telescope was adapted to the large instrument. With this micrometer, whose adjustment and errors of form were carefully attended to, the remaining positions were obtained. The comet was at no time a good object for observation, and in consequence of either bright moonlight or haze, such was particularly the case on Sept. 2, 7, 10, 11, 12; Oct. 6, 7, 11, 25 and 29. On Oct. 25 it approached so close to star No. 59 as to be observed with the greatest difficulty. On the whole I think the positions yielded by the square bar-micrometer will be found more satisfactory than those obtained with the ring. Finlay's comet was observed with the large Equatorial from Oct. 8 to Dec. 30.

I may add that the tail of a large comet was visible on the W.S.W. horizon immediately after sunset on the evenings of the 19th, 20th, and 21st inst. at several places in the neighbouring colonies. At Windsor, however, the past few days have been characterised by dense cloud, with rain, so that no opportunity whatever was afforded for getting even a glimpse of the stranger.

*Winnecke's Comet*, 1886.

| 1886. | | Windsor Mean Time. | Comet—Star. Δ R.A. | Δ N.P.D. | Comps. | Comet's App. R.A. | Log $\frac{\rho}{P}$ | Comet's App. N.P.D. | Log. $\frac{\varepsilon}{P}$ | Red. to App. Place. | | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h m s | m s | ′ ″ | | h m s | + | ° ′ ″ | + | s | ″ | |
| Aug. | 25 | 7 36 52 | +9 26·57 | −17 39·6 | 6 | 13 26 51·82 | 8·7070 | 94 2 0·6 | 9·7204 | +0·87 | +1·3 | 1 |
| | 25 | 7 36 52 | +8 6·55 | −17 16·4 | 6 | | 8·7070 | | 9·7204 | +0·87 | +1·2 | 2 |
| | 28 | 7 33 54 | −3 30·39 | − 9 16·3 | 9 | 13 37 58·72 | 8·7064 | 95 58 49·5 | 9·7088 | +0·97 | +0·6 | 3 |
| | 29 | 7 41 37 | −2 52·10 | + 2 37·9 | 7 | | 8·7134 | | 9·7073 | +0·98 | +0·5 | 4 |
| | 29 | 7 41 37 | −3 59·00 | + 2 25·7 | 7 | 13 41 47·91 | 8·7134 | 96 38 53·6 | 9·7073 | +0·98 | +0·4 | 5 |
| Sept. | 1 | 7 30 3 | −4 52·50 | | 4 | 13 53 27·82 | 8·7058 | | | +1·03 | +0·3 | 6 |
| | 1 | 7 30 3 | −7 14·28 | − 5 46·0 | 4 | 13 53 27·90 | 8·7058 | 98 40 22·7 | 9·6904 | +1·04 | +0·2 | 7 |
| | 2 | 7 22 57 | +1 50·73 | | 4 | 13 57 26·80 | 8·7000 | | | +1·02 | +0·6 | 8 |
| | 2 | 7 22 57 | −8 25·15 | − 4 3·5 | 4 | | 8·7000 | | 9·6823 | +1·06 | +0·1 | 9 |
| | 2 | 7 22 57 | −9 2·38 | − 0 23·7 | 4 | 13 57 27·70 | 8·7000 | 99 21 24·5 | 9·6823 | +1·07 | +0·1 | 10 |
| | 5 | 7 28 2 | −2 54·38 | − 4 31·3 | 8 | 14 9 47·67 | 8·7072 | 101 27 37·6 | 9·6690 | +1·09 | +0·3 | 11 |
| | 7 | 7 12 16 | −3 19·87 | + 1 55·9 | 9 | 14 18 15·89 | 8·6929 | 102 52 40·6 | 9·6466 | +1·12 | +0·1 | 12 |
| | 8 | 7 10 1 | +4 10·87 | + 1 58·8 | 8 | 14 22 36·35 | 8·6913 | 103 35 46·8 | 9·6382 | +1·10 | +0·4 | 13 |
| | 8 | 7 10 1 | +3 22·91 | + 1 33·0 | 8 | 14 22 36·33 | 8·6913 | 103 35 45·6 | 9·6382 | +1·11 | +0·4 | 14 |
| | 10 | 7 13 28 | +6 26·57 | − 4 42·2 | 4 | 14 31 29·87 | 8·6968 | 105 2 14·8 | 9·6263 | +1·13 | +0·4 | 15 |
| | 10 | 7 13 28 | +0 36·25 | + 1 34·3 | 4 | | 8·6968 | | 9·6263 | +1·15 | +0·2 | 16 |

| 1886. | Windsor Mean Time. | Comet—Star Δ R.A. | Comet—Star Δ N.P.D. | Comps. | Comet's App. R.A. | Log. $\frac{p}{P}$ | Comet's App. N.P.D. | Log. $\frac{q}{P}$ | Red. to App. Place. | | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | h m s | m s | ′ ″ | | h m s | + | ° ′ ″ | + | s | ″ | |
| Sept. 10 | 7 44 1 | +0 42·29 | | 3 | | 8·7255 | | | +1·15 | +0·2 | 16 |
| 10 | 7 44 1 | −8 4·20 | + 4 28·9 | 3 | 14 31 37·64 | 8·7255 | 105 3 11·3 | 9·6518 | +1·20 | +0·2 | 17 |
| 11 | 7 28 27 | +2 15·25 | + 3 50·4 | 7 | 14 36 6·74 | 8·7130 | 105 46 15·0 | 9·6316 | +1·16 | +0·2 | 18 |
| 11 | 7 28 27 | +1 51·65 | + 3 20·3 | 7 | 14 36 7·49 | 8·7130 | 105 46 12·7 | 9·6316 | +1·17 | +0·2 | 19 |
| 12 | 7 8 52 | +2 29·78 | + 6 5·4 | 7 | 14 40 39·93 | 8·6932 | 106 29 33·0 | 9·6058 | +1·18 | +0·1 | 20 |
| 12 | 7 8 52 | +0 59·72 | + 6 35·3 | 7 | | 8·6932 | | 9·6058 | +1·19 | +0·1 | 21 |
| 15 | 7 28 26 | −4 47·14 | − 0 27·5 | 8 | | 8·7167 | | 9·6003 | +1·27 | −0·3 | 22 |
| 15 | 7 34 32 | −4 52·29 | | 5 | | 8·7226 | | | +1·27 | −0·4 | 23 |
| 16 | 7 26 15 | −1 53·05 | + 0 44·1 | 10 | 14 59 56·45 | 8·7156 | 109 25 17·2 | 9·5891 | +1·28 | −0·3 | 24 |
| 16 | 7 26 15 | −5 47·88 | | 10 | 14 59 56·87 | 8·7156 | | | +1·30 | −0·5 | 25 |
| 17 | 7 14 43 | +1 35·19 | | 10 | 15 4 53·94 | 8·7039 | | | +1·28 | −0·2 | 26 |
| 17 | 7 14 43 | +1 9·65 | + 0 47·8 | 10 | | 8·7039 | | 9·5654 | +1·28 | −0·2 | 27 |
| 18 | 7 26 27 | −9 29·77 | − 6 23·2 | 4 | 15 10 1·35 | 8·7176 | 110 52 20·5 | 9·5705 | +1·36 | −0·7 | 28 |
| 20 | 7 25 51 | +4 36·25 | + 9 4·6 | 5 | 15 20 26·95 | 8·7186 | 112 18 28·3 | 9·5485 | +1·33 | −0·3 | 29 |
| 20 | 7 25 51 | +2 52·09 | − 0 33·2 | 5 | 15 20 25·98 | 8·7186 | 112 18 27·4 | 9·5485 | +1·34 | −0·3 | 30 |
| 20 | 7 32 10 | −2 10·51 | + 0 19·1 | 4 | | 8·7251 | | 9·5576 | +1·36 | −0·6 | 31 |
| 21 | 7 15 17 | −0 51·32 | − 3 43·1 | 10 | 15 25 43·17 | 8·7073 | 113 0 58·6 | 9·5209 | +1·38 | −0·6 | 32 |

| 1886. | | Windsor Mean Time. | Comet—Star Δ R.A. | Comet—Star Δ N.P.D. | Comps. | Comet's App. R.A. | Log. $\frac{p}{P}$ | Comet's App. N.P.D. | Log. $\frac{q}{P}$ | Red. to App. Place. | | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h m s | m s | ′ ″ | | h m s | + | ° ′ ″ | + | s | ″ | |
| Sept. | 22 | 7 20 35 | +2 50·96 | − 2 54·2 | 7 | 15 31 9·65 | 8·7141 | 113 43 24·2 | 9·5169 | +1·38 | −0·5 | 33 |
| | 22 | 7 20 35 | +1 17·15 | + 6 28·9 | 7 | 15 31 9·58 | 8·7141 | 113 43 22·7 | 9·5169 | +1·38 | −0·6 | 34 |
| | 22 | 7 20 35 | −1 17·10 | + 8 19·5 | 7 | 15 31 9·60 | 8·7141 | 113 43 19·5 | 9·5169 | +1·40 | −0·7 | 35 |
| | 23 | 7 20 19 | +5 3·09 | + 8 29·8 | 5 | 15 36 40·40 | 8·7143 | 114 25 13·4 | 9·5035 | +1·39 | −0·6 | 36 |
| | 23 | 7 20 19 | −2 23·77 | + 3 53·7 | 5 | 15 36 40·64 | 8·7143 | 114 25 14·1 | 9·5035 | +1·42 | −0·8 | 37 |
| | 24 | 7 24 5 | +3 18·67 | − 1 26·2 | 5 | 15 42 16·99 | 8·7192 | 115 6 40·6 | 9·4967 | +1·42 | −0·7 | 38 |
| | 24 | 7 24 5 | −4 30·29 | + 7 37·9 | 5 | 15 42 17·21 | 8·7192 | 115 6 44·9 | 9·4967 | +1·46 | −1·0 | 39 |
| | 28 | 7 7 0 | +0 12·53 | + 7 54·6 | 10 | 16 5 31·03 | 8·6971 | 117 45 38·4 | 9·3984 | +1·52 | −1·2 | 40 |
| | 28 | 7 27 43 | +0 18·14 | + 8 23·5 | 3 | 16 5 36·64 | 8·7245 | 117 46 7·3 | 9·4454 | +1·52 | −1·2 | 40 |
| | 28 | 7 27 43 | −5 38·56 | + 0 36·8 | 3 | 16 5 36·68 | 8·7245 | 117 46 8·4 | 9·4454 | +1·55 | −1·4 | 41 |
| | 30 | 7 18 16 | −0 48·34 | − 7 19·5 | 8 | 16 17 44·24 | 8·7121 | 119 0 51·7 | 9·3887 | +1·57 | −1·4 | 42 |
| | 30 | 7 18 16 | −2 39·05 | − 0 52·2 | 8 | 16 17 44·39 | 8·7121 | 119 0 52·0 | 9·3887 | +1·58 | −1·6 | 43 |
| Oct. | 1 | 7 32 2 | +1 31·13 | + 0 37·3 | 4 | 16 24 0·75 | 8·7295 | 119 37 22·5 | 9·4055 | +1·58 | −1·5 | 44 |
| | 1 | 7 32 2 | −0 32·46 | − 1 0·7 | 4 | 16 24 0·85 | 8·7295 | 119 37 20·9 | 9·4055 | +1·59 | −1·6 | 45 |
| | 5 | 7 27 28 | +0 6·56 | + 2 12·9 | 8 | | 8·7205 | | 9·3126 | +1·68 | −2·1 | 46 |
| | 5 | 7 27 28 | −4 49·66 | − 7 44·4 | 8 | 16 49 42·38 | 8·7205 | 121 50 34·1 | 9·3126 | +1·70 | −2·3 | 47 |
| | 6 | 7 41 23 | +0 12·58 | − 5 39·8 | 5 | | 8·7378 | | 9·3364 | +1·70 | −2·2 | 48 |

| 1886. | | Windsor Mean Time. | Comet—Star Δ R.A. | Comet—Star Δ N.P.D. | Comps. | Comet's App. R.A. | Log. $\frac{p}{P}$ | Comet's App. N.P.D. | Log. $\frac{q}{P}$ | Red. to App. Place. | | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h m s | m s | ′ ″ | | h m s | + | ° ′ ″ | + | s | ″ | |
| Oct. | 6 | 7 42 12 | +2 8·75 | − 7 21·4 | 3 | 16 56 23·75 | 8·7388 | 122 21 13·0 | 9·3390 | +1·69 | −2·2 | 49 |
| | 7 | 8 19 0 | −1 59·98 | + 2 9·9 | 15 | | 8·7776 | | 9·4325 | +1·73 | −2·5 | 50 |
| | 7 | 8 19 0 | −3 5·90 | + 7 58·3 | 15 | | 8·7776 | | 9·4325 | +1·73 | −2·6 | 51 |
| | 11 | 8 33 5 | +1 40·83 | + 0 46·8 | 13 | | 8·7883 | | 9·4115 | +1·79 | −3·1 | 52 |
| | 11 | 8 33 5 | −0 50·18 | + 7 37·8 | 13 | | 8·7883 | | 9·4115 | +1·80 | −3·2 | 53 |
| | 21 | 8 47 16 | +4 4·68 | + 5 17·5 | 14 | 18 40 31·77 | 8·7859 | 126 54 51·5 | 9·3033 | +1·93 | −5·0 | 54 |
| | 21 | 8 47 16 | −2 18·26 | − 1 37·6 | 14 | 18 40 31·71 | 8·7859 | 126 54 52·2 | 9·3033 | +1·96 | −5·2 | 55 |
| | 23 | 9 27 0 | +3 25·89 | −11 5·1 | 12 | 18 54 30·18 | 8·8157 | 127 4 4·5 | 9·4260 | +1·96 | −5·4 | 56 |
| | 23 | 9 27 0 | +1 6·78 | − 8 48·3 | 12 | 18 54 29·70 | 8·8157 | 127 4 6·3 | 9·4260 | +1·97 | −5·5 | 57 |
| | 23 | 10 0 30 | −4 5·61 | − 9 14·1 | 4 | 18 54 39·03 | 8·8338 | 127 4 13·2 | 9·5278 | +1·99 | −5·6 | 58 |
| | 25 | 8 26 59 | +9 1·22 | − 6 20·9 | 6 | 19 7 45·82 | 8·7486 | 127 7 6·4 | 9·1456 | +1·95 | −5·6 | 58 |
| | 25 | 8 26 59 | −0 11·82 | − 1 25·3 | 6 | 19 7 45·75 | 8·7486 | 127 7 7·0 | 9·1456 | +1·99 | −5·9 | 59 |
| | 25 | 8 26 59 | −4 0·02 | + 1 15·4 | 6 | 19 7 46·17 | 8·7486 | 127 7 5·1 | 9·1456 | +2·01 | −6·0 | 60 |
| | 25 | 9 22 13 | +0 4·45 | − 1 22·0 | 8 | 19 8 2·02 | 8·8083 | 127 7 10·3 | 9·3891 | +1·99 | −5·9 | 59 |
| | 27 | 8 27 55 | +9 19·18 | − 1 22·5 | 10 | 19 21 5·33 | 8·7419 | 127 4 27·1 | 9·1229 | +1·97 | −6·1 | 60 |
| | 27 | 8 27 55 | +0 15·01 | − 8 32·1 | 10 | | 8·7419 | | 9·1229 | +2·01 | −6·3 | 61 |
| | 29 | 7 43 20 | −0 47·22 | + 2 58·9 | 6 | 19 33 53·80 | 8·6503 | 126 56 36·1 | 8·7473 | +2·02 | −6·7 | 62 |

*Mean places of the Comparison Stars for* 1886·0.

| Star. | R.A. h m s | N.P.D. ° ′ ″ | Authorities. |
|---|---|---|---|
| 1 | 13 17 24·38 | 94 19 38·9 | Cape Cat. 1850, 2383; Yarnall 5535; Gr. 7 Yr. Cat. 1864, 1569; Glasgow 3366; Gr. 9 Yr. Cat. 1872, 1223. |
| 2 | 13 18 44 | 94 19 | Approx. Position per Equatorial, Star = 8 mag. |
| 3 | 13 41 28·14 | 96 8 5·2 | Cape Cat. 1850, 2451; Yarnall 5670; Schj. 4916 and 4917. |
| 4 | 13 44 39 | 96 36 | Approx. Position per Equatorial, Star = 8½ mag. |
| 5 | 13 45 45·93 | 96 36 27·5 | Lamont$_5$, 1568; Schj. 4947. |
| 6 | 13 58 19·29 | 98 42 34·5 | Cape Cat. 1850, 2503; Yarnall 5812. |
| 7 | 14 0 41·14 | 98 46 8·5 | Gr. Cat. 1850, 883; Cape Cat. 1850, 2511; 2nd Rad. Cat. 1355; Gr. 9 Yr. Cat. 1872, 1285. |
| 8 | 13 55 35·05 | 99 23 19·6 | Lamont$_5$, 1442. |
| 9 | 14 5 52 | 99 25 | Approx. Position per Equatorial, Star = 8 mag. |
| 10 | 14 6 29·01 | 99 21 48·1 | Cape Cat. 1850, 2525; 2nd Rad. Cat. 1365; Gr. 9 Yr. Cat. 1864, 1639; Glasgow 3521. |
| 11 | 14 12 40·96 | 101 32 8·6 | Schj. 5089. |
| 12 | 14 21 34·64 | 102 50 44·6 | Cape Cat. 1850, 2570; Radcliffe Obs. 1873, 729, and 1874, 800. |
| 13 | 14 18 24·38 | 103 33 47·6 | Yarnall 5946. |
| 14 | 14 19 12·31 | 103 34 12·2 | Yarnall 5955. |
| 15 | 14 25 2·17 | 105 6 56·6 | Lamont$_5$, 1570. Lalande's position differs considerably from Lamont's. |
| 16 | 14 30 53 | 105 1 | Approx. Position per Equatorial, Star = 9½ mag. |
| 17 | 14 39 40·64 | 104 58 42·2 | Cape Cat. 1850, 2618; 2nd Rad. Cat. 1418; Yarnall 6071; Gr. 7 Yr. Cat. 1864, 1677; Gr. 9 Yr. Cat. 1872, 1332; Rad. Obs. 1874, 810. |
| 18 | 14 33 50·33 | 105 42 24·4 | Lalande 26702. |

| Star. | R.A. h m s | N.P.D. ° ′ ″ | Authorities. |
|---|---|---|---|
| 19 | 14 34 14·67 | 105 42 52·2 | Lalande 26706 and 26707; Lamont$_8$, 264. |
| 20 | 14 38 8·97 | 106 23 27·5 | Arg.-Oeltzen 13891. |
| 21 | 14 39 39 | 106 23 | Approx. Position per Equatorial, Star = 9 mag. |
| 22 | 14 59 50 | 108 41 | „ „ „ Star = 8½ „ |
| 23 | 14 59 57 | 108 38 | „ „ „ Star = 8½ „ |
| 24 | 15 1 48·22 | 109 24 33·4 | Arg.-Oeltzen 14280 and 14281. |
| 25 | 15 5 43·45 | 109 21 33·9 | Arg.-Oeltzen 14348; Rad. Cat. 1845, 3329; Cape Cat. 1850, 2695; 2nd Rad. Cat. 1459; Yarnall 6246; Gr. 7 Yr. Cat. 1864, 1710; Gr. 9 Yr. Cat. 1872, 1365; Stone 8261; Rad. Obs. 1874, 832, and 1882, 332; Cape Obs. 1880, 282, and 1881, 438. |
| 26 | 15 3 17·47 | 110 4 53·5 | Lalande 27567. |
| 27 | 15 3 43 | 110 8 | Approx. Position per Equatorial, Star = 9 mag. |
| 28 | 15 19 29·76 | 110 58 44·4 | Arg.-Oeltzen 14544 and 14545; Wash. Mural Cir. Zone 259, 8; Yarnall 6342. |
| 29 | 15 15 49·37 | 112 9 24·0 | Wash. Mural Cir. Zone 252, 22. |
| 30 | 15 17 32·55 | 112 19 0·9 | Arg.-Oeltzen 14513; Wash. Mural Cir. Zone 252, 24; Yarnall 6328; Washburn-Palermo Cat. 530. 2 secs. have been subtracted from the W. Mural Cir. Zone R.A. |
| 31 | 15 22 37 | 112 18 | Approx. Position per Equatorial, Star = 9 mag. |
| 32 | 15 26 33·11 | 113 4 42·3 | Arg.-Oeltzen 14643; Wash. Mural Cir. Zone 175, 11. 1 min. has been added to the R.A. of Wash. Mural Cir. Zone. |
| 33 | 15 28 17·31 | 113 46 18·9 | Wash. Mural Cir. Zone 174, 14; Washburn-Palermo Cat. 540. |
| 34 | 15 29 51·05 | 113 36 54·4 | Wash. Mural Cir. Zone 174, 15; Washburn-Palermo Cat. 542. 1′ has been added to Wash. Mural Cir. Zone N.P.D. |
| 35 | 15 32 25·30 | 113 35 0·7 | Arg.-Oeltzen 14728. |

| Star. | R.A. | N.P.D. | Authorities. |
|---|---|---|---|
| | h m s | ° ′ ″ | |
| 36 | 15 31 35·92 | 114 16 44·2 | Arg.-Oeltzen 14715; Wash. Merid. Tr. Zone 239, 25. The N.P.D.s are discordant. |
| 37 | 15 39 2·99 | 114 21 21·2 | Arg.-Oeltzen 14840; Cape Cat. 1850, 2831; 2nd Rad. Cat. 1515; Gr. 9 Yr. Cat. 1872, 1406; Stone 8559. |
| 38 | 15 38 56·90 | 115 8 7·5 | Arg.-Oeltzen 14838; Wash. Merid. Tr. Zone 166, 15; Wash. Mural Cir. Zone 165, 62. |
| 39 | 15 46 46·04 | 114 59 8·0 | Arg.-Oeltzen 14974 and 5; Wash. Merid. Tr. Zone 166, 18; Wash. Mural Cir. Zone 165, 66; Washburn-Palermo Cat. 563; Cape Cat. 1850, 2866; Yarnall 6544; 2nd Rad. Cat. 1521; Gr. 7 Yr. Cat. 1864, 1780; Gr. 9 Yr. Cat. 1872, 1416; Armagh 1852; Stone 8628; Rad. Obs. 1882, 353. The Wash. Mural Cir. Z. R.A. and Wash. Merid. Tr. Z. N.P.D. rejected. |
| 40 | 16 5 16·98 | 117 37 45·0 | Arg.-Oeltzen 15351; Cape Cat. 1850, 2957; Wash. Mural Cir. Zone 29, 13; Yarnall 6691; 2nd Rad Cat. 1552; Stone 8807; Rad. Obs. 1880, 351; Cape Obs. 1881, 468. |
| 41 | 16 11 13·69 | 117 45 33·0 | Arg.-Oeltzen 15482; Cape Cat. 1850, 2992; Wash. Mural Cir. Zone 29, 16; Yarnall 6731; Rad. Obs. 1872, 777; 1874, 900; 1875, 694; 1876, 695; Stone 8858. |
| 42 | 16 18 31·01 | 119 8 12·6 | Arg.-Oeltzen 15609, 10, and 11; Cape Cat. 1850, 3022; Wash. Merid. Tr. Zone 117, 8; Wash. Merid. Cir. Zone 94, 22; Wash. Mural Cir. Zone 263, 16; Yarnall 6784; Rad. Obs. 1872, 786; Stone 8931. |
| 43 | 16 20 21·86 | 119 1 45·8 | Arg.-Oeltzen 15643, 4, and 5; Cape Cat. 1850, 3030; Wash. Merid. Tr. Zone 117, 9; Wash. Merid. Cir. Zone 94, 25; Wash. Mural Cir. Zone 263, 19; Yarnall 6794; 2nd Rad. Cat. 1578; Stone 8941. Wash. Merid. Tr. Z. R.A. rejected. There appears to be a systematic error of 1ˢ in the Right Ascension of this zone. |
| 44 | 16 22 28·04 | 119 36 46·7 | Arg.-Oeltzen 15662; Wash. Merid. Tr. Zone 17, 86; Wash. Merid. Cir. Zone 97, 91; Wash. Mural Cir. Zone 263, 20. |
| 45 | 16 24 31·72 | 119 38 23·2 | Arg.-Oeltzen 15694; Wash. Merid. Tr. Zone 17, 88; Wash. Mural Cir. Zone 263, 24; Yarnall 6809. The authorities are very discordant. |
| 46 | 16 49 34 | 121 48 | Approx. Position per Equatorial, Star = 8 mag. |

| Star. | h m s | ° ′ ″ | |
|---|---|---|---|
| 47 | 16 54 30·34 | 121 58 20·8 | Cape Cat. 1850, 3178; Wash. Merid. Tr. Zone 30, 26; Yarnall 7043; Stone 9253; Rad. Obs. 1880, 370. |
| 48 | 16 56 9 | 122 27 | Approx. Position per Equatorial, Star = 9 mag. |
| 49 | 16 54 13·31 | 122 28 36·6 | Wash. Mural Cir. Zone 25, 24. |
| 50 | 17 5 13 | 122 49 | Approx. Position per Equatorial, Star = 9 mag. |
| 51 | 17 6 19 | 122 43 | " " " Star = $8\frac{1}{2}$ " |
| 52 | 17 28 54 | 124 32 | " " " Star = 9 " |
| 53 | 17 31 25 | 124 25 | " " " Star = $8\frac{1}{2}$ " |
| 54 | 18 36 25·16 | 126 49 39·0 | Wash. Merid. Tr. Zone 56, 9; Stone 10182. |
| 55 | 18 42 48·01 | 126 56 35·0 | " " 56, 11. |
| 56 | 18 51 2·33 | 127 15 15·0 | Cape Cat. 1850, 3716; Wash. Merid. Tr. Zone 56, 13; Wash. Mural Cir. Zone 48, 25; Melb. Cat. 1870, 961; Stone 10309. |
| 57 | 18 53 20·95 | 127 13 0·1 | Wash. Merid. Tr. Zone 56, 14; Wash. Mural Cir. Zone 48, 26; Yarnall 8056; Stone 10326. |
| 58 | 18 58 42·65 | 127 13 32·9 | Cape Cat. 1850, 3745; Wash. Merid. Tr. Zone 56, 18; Wash. Mural Cir. Zone 48, 28; Yarnall 8108; Melb. Obs. 1880, 302; Stone 10373. |
| 59 | 19 7 55·58 | 127 8 38·2 | Wash. Merid. Tr. Zone 56, 19; Wash. Mural Cir. Zone 48, 33; Yarnall 8187; Stone 10440. |
| 60 | 19 11 44·18 | 127 5 55·7 | Wash. Merid. Tr. Zone 56, 20; Wash. Mural Cir. Zone 48, 34; Yarnall 8223; Stone 10459. |
| 61 | 19 20 49 | 127 13 | Approx. Position per Equatorial, Star = 9 mag. |
| 62 | 19 34 39·00 | 126 53 43·9 | Wash. Merid. Tr. Zone 56, 23; Cordoba Zone 22, 2; Yarnall 8437; Stone 10615. 1′ has been subtracted from the first authority for N.P.D. |

*Windsor, N. S. Wales:*
1887, *January* 24.

## *Elements of Comet* 1886 *e* (*Finlay*). By W. H. Finlay, M.A.

The following elements represent my observations of this comet closely. A normal place was deduced from the observations on September 26, 27, 29, and 30, and another from those on December 13, 15, 16 and 17; these were:

| | | |
|---|---|---|
| Sept. 28·5 | $\alpha = 256^\circ\ 48'\ 38''\cdot2$ | $\delta = -26^\circ\ 10'\ 51''\cdot0$ |
| Dec. 15·5 | $\alpha = 336\ 51\ 52\cdot2$ | $\delta = -10\ 49\ 16\cdot0$ |

From these, by varying the geocentric distances to satisfy the observations on October 21, November 13, and December 27 (on which dates very good places were available for the comparison stars), I obtained the elements

T = Nov. 22·3918, G.M.T.

| | | |
|---|---|---|
| $\omega$ | $315^\circ\ 5'\ 47''\cdot0$ | Ecliptic and Mean Equinox 1886·0 |
| ☊ | $52\ 29\ 15\cdot2$ | |
| $i$ | $3\ 1\ 38\cdot6$ | |
| $\phi$ | $45\ 51\ 51\cdot6$ | |
| $\log a$ | $0\cdot5482066$ | |
| $\mu$ | $534''\cdot1911$ | |

The representation of the observations on October 21, November 13, and December 27 is

| | C−O: $d\lambda$ as $\beta$ | C−O: $d\beta$ |
|---|---|---|
| Oct. 21 | $+0''\cdot7$ | $+3''\cdot3$ |
| Nov. 13 | $+0\cdot6$ | $+5\cdot1$ |
| Dec. 27 | $-0\cdot8$ | $-2\cdot9$ |

I discontinued my observations when the comet passed to the north of the equator, and was more favourably situated for observation in the northern hemisphere, so that I have no later date than December 27 to compare with the elements. The discordances in latitude are persistent in all the variations of the distances. The heliocentric co-ordinates are

$$x = [9\cdot9996185]\ r \sin\ (97^\circ\ 32'\ 43''\cdot0 + v)$$
$$y = [9\cdot9562980]\ r \sin\ (8\ 40\ 46\cdot9 + v)$$
$$z = [9\cdot6324689]\ r \sin\ (2\ 28\ 49\cdot5 + v)$$

*Royal Observatory, Cape of Good Hope:*
1887, *February.*

## *Comet* 1887 *a*. By W. H. Finlay, M.A.

tail of this remarkable comet was first seen, so far as I ire, by a farmer and a fisherman at Blauwberg (near own), on Tuesday night, January 18; the next evening een at Grahamstown, Fraserburg, &c.; our first view of ie observatory was on January 22. It presented the nce of a pale narrow ribbon of light, quite straight, and y uniform brightness throughout its length. There was or condensation of any kind visible near the end, the nply fading away to nothing. The comet was lost in the Equatorial long before the end of the light, as visible to ed eye, was reached. The following rough observations ide by tracing the tail down as far as possible with the f the 6-inch and reading the circles of the Equatorial. uary 24 and 27 the circles were also read for the centre y slightly more condensed part of the tail, extending over ialf a degree. A star near the same position was also d in a similar manner each evening. The resulting re:

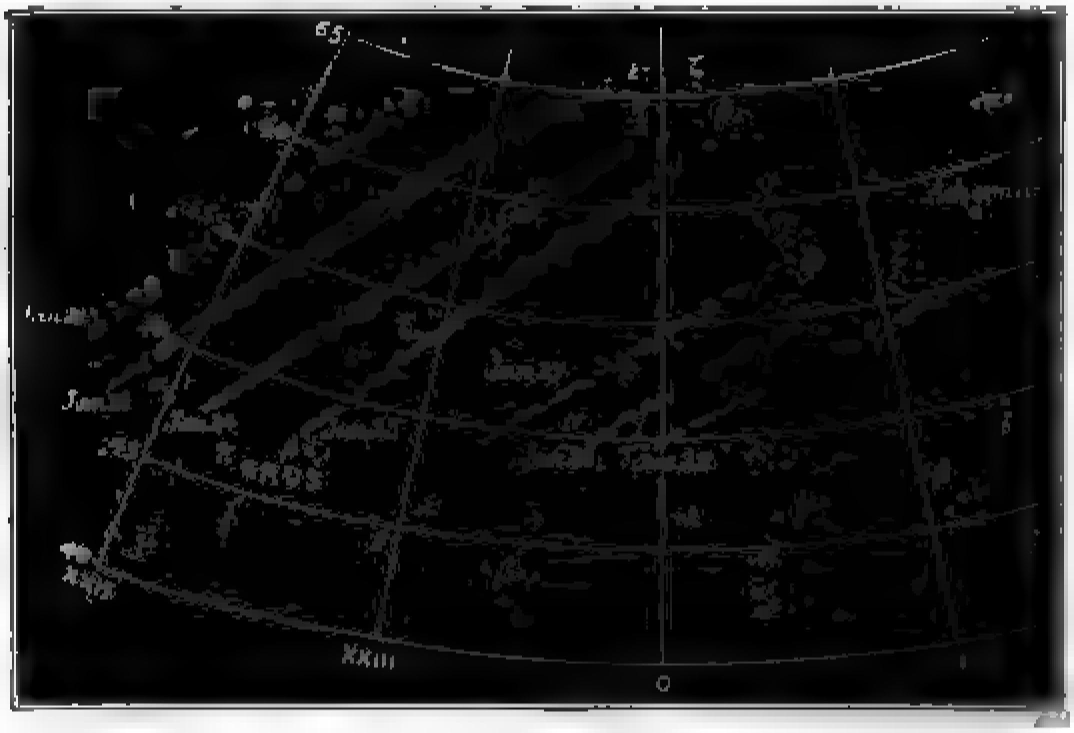
| Date. | Cape M.T. | App. R.A. | App. Dec. |
|---|---|---|---|
| | h m | h m s | ° ′ |
| Jan. 22 | 8 50 | 21 30 0 | −45 47½ |
| 23 | 8 44 | 21 47 54 | −46 32½ |
| 24 | 8 50 | 22 8 15 | −47 35 |
| 24* | 8 55 | 22 9 20 | −47 54½ |
| 25 | 9 4 | 22 30 44 | −48 39 |
| 27 | 8 58 | 23 16 10 | −49 38 |
| 27* | 9 35 | 23 17 11 | −49 50 |
| 28 | 9 38 | 23 37 12 | −49 22 |

observations marked * are of the centre of the slightly part of the tail. Moonlight put a stop to any further ions. The tail was sketched each night on a map from Gould's *Uranometria*; it was quite straight at first, the 27th, 28th, and 29th a slight curvature was per-

physical appearance of the comet, its long straight tail eater brilliancy than the smaller Magellanic cloud, and ence of head at once recalled to mind the comet of y 1880, and as soon as I had secured a place on 22 I tried whether the observed place could result ie elements of that comet. I found that it could very vith a true anomaly of 168°·7 and perihelion passage

Z

January 11·0, and the comet's subsequent motion is very similar to what would result from these elements.




| | | |
|---|---|---|
| 1887, January 22, $8^h\ 50^m$ G.M.T. | | January 27, $9^h\ 15^m$ G.M.T. |
| " 23, $9^h\ 5^m$ " | | " 28, $9^h\ 35^m$ " |
| " 24, $9^h\ 15^m$ " | | " 29, $9^h\ 15^m$ " |
| " 25, $9^h\ 30^m$ " | | |

From the observations on January 22, 25, and 28 I find the following orbit:

$$T = \text{Jan } 11^d{\cdot}244, \text{ G.M.T.}$$

$$\begin{array}{ll} \pi & 89^\circ\ 41' \\ \Omega & 359\ \ 41 \\ i & 141\ \ 16 \\ q & 0{\cdot}0146 \end{array}$$

This orbit satisfies the middle place in longitude, but leaves discordance of 4′ in latitude. These elements, though of course rough, prove conclusively that the comet belongs to the family of 'Sun-grazers,' of which 1843 I., 1880 I., and 1882 II. are members.

*Royal Observatory, Cape of Good Hope:*
1887, *February* 14

## *Observations of Comet 1887 a, made at the Observatory, Adelaide.* By Charles Todd.

*(Extracts from letters to the Astronomer Royal.)*

A few words about the new comet which has suddenly burst into view in the S.W. I sent you a telegram through Mr. Hesse on Friday, the 21st, which I hope you received, and I now enclose a rough sketch-map showing its positions on Jan. 20th to Jan. 27th. It was first seen on the 19th, but at the Observatory, by myself, not till the 20th, shortly before 9 P.M. The head of the comet was then hid by the mists of the horizon, but the tail passed nearly midway between *α Gruis* and *α Pavonis*, or over *γ Indi*, extending to and a little to the right of *γ Pavonis*.


On the 21st it was better seen and the head of the comet was close to a small star, or roughly (at 9 P.M.) R.A. $21^h\ 5^m$, Decl. $42°\ 34'$. The tail of the comet, as measured round the horizon, had sensibly moved to the north or towards *α Grus*; it passed a little to the right of *γ Indi*, and to the left of *α* and *δ Toucani*, and could be traced a little higher in the direction of *β Hydri*. On the 22nd, at $8^h\ 30^m$, the position of the head of the comet was roughly R.A. $21^h\ 20^m\ 30^s$, Decl. $44°\ 17'$. The comet has a long narrow tail of about 30°, but no well-defined nucleus, resembling, in fact, very closely in appearance the comet of Feb. 1880, which during its short season of visibility, you will remember, occupied the same part of the sky, and came into view equally suddenly. I will follow it up on every clear night and advise you again. In the meantime this will be useful in comparing with observations made elsewhere, and may, perhaps, be of some use in getting a rough orbit.

The following are the only positions of the comet I was able to secure before the Moon shut it out. Although a conspicuous object, about as bright at first as the Magellan clouds, it became rapidly fainter, and at no time was there any defined nucleus* or condensation about the head. It was simply a narrow nebulous streak of about 30° long, and although with the naked eye, or with an ordinary field-glass, the position of the head of the comet could be fairly determined, yet seen through the Equatorial the head was so diffused and died away so gradually that it was quite impossible to say where it was. The positions I give are consequently mere rough approximations obtained by the Equatorial, checked by the naked eye.

On the 24th, at 9 P.M., the head of the comet was partly over and a little to the right of *α Gruis*, which star appeared as bright stellar nucleus.

On the 20th the head was in the midst of the group $\tau^1$, $\tau^2$, *Gruis*, the tail passing between *h2* and 58, and over *ι Toucani* an to the left of *α Hydri*.

On the 27th the head of the comet, a very diffused nebulo mass, appeared to be cut off by a wide break or rift, from the t and higher up there was another narrow break in the continu of the tail. Both of these breaks might be attributable to sm clouds, but we could see faint stars through the breach wh seemed to forbid such a supposition :

| | | R.A. | Dec. |
|---|---|---|---|
| | h | h m | ° ′ |
| Jan. 21 | 9 | 21 5 | −42 34 |
| 22 | 9 | 21 21 | 44 17 |
| 25 | 9½ | 22 22 | 48 18 |
| 26 | 9·40 | 22 47 | 49 14 |
| 27 | 9·15 | 23 9 | 49 39 guess work |

I shall be curious to know how these agree with, perh better, positions obtained elsewhere. I send them hoping t may at least be useful in identifying the comet which I disposed to regard as a fragment of some previous visitor.

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*The Moon and Aldebaran*, 1887, *March* 2, $5^h\ 45^m$ *to* $6^h\ 0^m$ *G.M.T.* *as seen at the Radcliffe Observatory, Oxford.* By E. J. Stone, M.A., F.R.S.

The occultation of *Aldebaran* by the Moon predicted to take place on 1887, March 2, was carefully looked for at the Radcliffe Observatory, but though an extraordinarily near appulse took place there was no occultation at Oxford. The overlapping of

* A nucleus was observed by Mr. Eddie of Grahamstown, on Jan. 24, 25, and 26.—ED.

the image of the Moon's limb and the diffraction image of the star appears to render a record of these observations desirable.

The following notes were made by the observers:

*Mr. Wickham*, with heliometer, $7\frac{1}{2}$-inch object-glass, and power = 200:

'The star did not disappear, but skirted the north limb. The exterior flames of the star's image on the side next the Moon were, at times, lost in the Moon's disc, although there was a strong contrast between the quality of the Moon's light and that of the star. The Moon's colour was a dead creamy white, the star's a brilliant light orange. The close contact of the star's disc to that of the Moon lasted without apparent change for nearly three minutes. The nearest appulse took place close to the division of the illuminated and defective limbs. There was very strong twilight.'

*Mr. Robinson*, with Marlborough telescope, $3\frac{1}{4}$-inch object-glass, and power = 80:

'The star was not occulted, but it apparently grazed the Moon's N. limb; three or four minutes previous to this, or about $5^h\ 47^m$ G.M.T., the Moon's periphery when produced beyond the N. cusp appeared to bisect the star. The dark limb of the Moon was not visible owing to twilight. The colour of the star greatly contrasted with that of the Moon, being orange-red throughout.'

*Mr. Bellamy*, with 10-foot telescope, 7-inch object-glass, power 125:

'The star was not occulted, but the outer rings of the image were, at times, in contact with and a small portion lost sight of in the illumination of the Moon's limb. The time when I estimated that the star was nearest the bright limb of the Moon was about $5^h\ 51\frac{1}{2}^m$ G.M.T.'

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## *Note on the Near Approach of Moon to a Tauri.*
## By Thomas Gwyn Elger.

Though this object was not actually occulted here on March 2, the exceedingly near approach of the Moon and star was watched with much interest, as it seemed probable, when the time drew near, that it might suffer a momentary eclipse by some of the elevations on the Moon's northern limb. Between $5^h\ 49^m$ and $5^h\ 54^m$ it appeared to be almost in contact with one of these, without, however, its light being visibly affected. The position of my observatory, according to the 6-inch scale map of the Ordnance Survey, is N. Lat. 52° 7′ 10″, W. Long. 2 mins. 0·4 sec. A power of 150 was used on a $8\frac{1}{2}$-inch Calver Reflector.

*Kempston, Beds:*
1887, *March* 5.

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## *Second Occultation of Aldebaran*, 1887. By the Rev. S. J. Johnson.

In marked contrast to the occultation period of 1866–9, when only one emersion of *Aldebaran* was visible from my place of observation and no immersion, the second passage of the Moon over the star visible here this year, on March 2, was seen under a sky even more favourable than the first. Parallax slightly lengthened the duration as compared with Greenwich. Immersion $5^h\ 40^m\ 53^s$, quite as instantaneous as last January. Sun had reached the horizon but had not descended. At $6^h\ 0^m\ 56^s$ *Aldebaran* clear of the Moon's limb, but visible on the bright edge five seconds before this. The illusion conveyed to the eye at emersion, probably from the smallness of the instrument and power, 50 on $3\frac{1}{4}$ inches, was that the star was shining through the bright limb. The only time I have had this impression before was during the totality of the eclipse of August 23, 1877, when three or four small stars appeared within the reddened disk for 8 or 10 seconds before actually disappearing. The same impression appears to have been conveyed to the eyes of observers at Greenwich and elsewhere on the occasion of the occultation of October 15, 1829.

*Melplash Vicarage, Dorset:*
*March* 9.

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## *The Occultation of Aldebaran.* By C. Leeson Prince.

I observed the occultation of *Aldebaran* this evening under very favourable circumstances; the Moon being so near the meridian, the Sun had just set, and the atmosphere was very calm, clear, and diaphanous; nevertheless, the non-illuminated portion of the Moon was not visible.

The disappearance occurred at $4^h\ 25^m\ 57^s$, and the reappearance at $4^h\ 48^m\ 37^s$, local sidereal time. The star was occulted, therefore, exactly $22^m\ 40^s$.

The disappearance was absolutely instantaneous, but the reappearance not quite so, a very minute point of light being visible for nearly a second before the star completely emerged; this may perhaps have been occasioned by a slight elevation on the lunar surface at the exact point of reappearance. Telescope 6·8 inches aperture, focal length, 12 feet; mag. power, 144.

*The Observatory, Crowborough, Sussex:*
1887, *March* 2.

# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY.

VOL. XLVII. APRIL 6, 1887 No. 6

EDWIN DUNKIN, F.R.S., Vice-President, in the Chair.

The Rev. John Bone, St. Thomas's Vicarage, Lancaster;

W. F. Caborne, Lieut. R.N.R., F.R.G.S., F.R.Met.Soc., 4 Cambridge Gardens, Notting Hill, and Royal Navy Club, Grafton Street, W.;

Campbell M. W. Hepworth, Lieut. R.N.R., 60 Matlock Lane, Ealing Dean; and

William Frederick Smith, F.R.Hist.Soc., 51 Perham Road, West Kensington, S.W.,

were balloted for and duly elected Fellows of the Society.

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## *On the Choice of Instruments for Stellar Photography.*

By Howard Grubb, F.R.S.

In view of the Astronomical Congress about to be held in Paris, the subject matter of its deliberations, viz. stellar photography, is naturally attracting much attention at present among astronomers; and I venture to hope that a few notes which I have put together on this subject may not be without interest to the Fellows of the Society. At the same time I desire to premise that I submit them, not with an idea that they possess any peculiar originality, but more as suggestions, and as tending to show the great number and diversity of points which will require to be thoroughly discussed before coming to a satisfactory conclusion as to the best instrumental equipment to satisfy all the conditions which arise in undertaking this new class of astronomical work.

The first and most important question to be decided is whether a refracting or reflecting telescope is likely to give the best results. Theoretically considered, the reflector would appear to have a considerable advantage, for in it there is no *dispersing* of the rays. If the spherical aberration be properly corrected, *all the rays* are brought to the same focus; whereas in the refractor it is not so. If the curve formed by the foci of the different rays of the spectrum be examined, in the case of a refractor, it will be seen that with any possible combination of existing glasses, or arrangements of same, a very small portion only of the whole light can be brought to one focus on the photographic plate; again, the field of the reflector is theoretically flatter; but at the same time, as pointed out by Lieut.-Gen. Tennant at last meeting, a considerable amount of "coma" is to be found in lateral pencils of the reflector, which coma causes distortion of the star discs.

Generally, however, the advantage appears to be on the side of the reflector. It was for these reasons that, when consulted some time ago by Mr. Roberts of Liverpool, I advised his adoption of the reflector in preference to the refractor for photographic purposes.

The value of Lieut.-Gen. Tennant's papers would have been largely increased had he gone a little further, and shown what the *comparative* results would be for the lateral pencils of a refractor. Nor would this be at all impracticable; for, although the result may vary with different constructions of objectives, it would still have been interesting to study the effect on the one ordinary form of double objective (corrected, of course, for chemical rays) such as I have constructed for Dr. Gill, and such as is, I believe, also used by the MM. Henry. At the time I came to the above conclusion respecting the superiority of the reflector I had nothing to guide me but deductions from theoretical considerations. Since then, however, the work of the MM. Henry at Paris, and Dr. Gill at Cape-Town, with refractors, and Mr. Roberts at Liverpool, with a reflector, present some practical results from which to draw further deductions, and while I readily admit that the refractors have done better work than I had expected, I am by no means prepared to admit without further demonstration that under equal conditions they may be expected to do *better* work than the reflectors.

I have not myself had an opportunity of comparing the negatives taken by the reflector and refractor; but I understand from those who have that while the star discs in Roberts' (reflector) photographs show in all parts a slight want of symmetry, there is no decided elongation of the discs up to 80′ from centre of field, whilst in the refractor photographs there is a decided distortion at that distance. The want of perfect symmetry in Roberts' photographs is probably due to the fact that the power of his finder, as compared to the main telescope, is not nearly so great as is used in the case of the refractor.

No doubt Mr. Roberts has not produced the same number of equally fine plates as the MM. Henry; but when we wish to compare results with a view of drawing a comparison between the value of the instruments which have produced those results, it is right and just to take the best specimens of each (not the average), for the inferiority of any examples which are of an excellence less than the best must be attributed to some unfavourable conditions outside the instrument, not in it. An inferior instrument cannot, under any circumstances, give a good result; and Mr. Roberts' best specimens appear to me to compare very favourably with those done by the refractors.

In making the comparison due regard must be had to the fact that the atmosphere of Liverpool is of very inferior quality as compared to that of either Paris or Cape-Town, and also that Mr. Roberts' photographs show an enormously increased number of stars on account of the large aperture of his instrument; but that very large aperture requires of course a still greater degree of perfection of atmosphere in order that its full power may be utilised.*

I do not for a moment dispute the fact that most excellent results can be, and have been, produced by a refractor; but it appears to me that it would be very unwise to spend large sums of money in the installation of several large refractors over the world without some further and more crucial comparative experiments as to the relative fitness of refractor and reflector for this particular work. Mr. Roberts has certainly shown that most excellent work can be done with the reflector; but his instrument is not comparable with the refractors which have been at the same work either as regards size, position, or many other respects.

It is, no doubt, highly desirable that the important work of mapping the heavens should be commenced with as little delay as possible; but it would be equally regrettable if in the beginning a large amount were expended on instruments which proved after a little to be not *the very best* for the purpose. I would venture to suggest, therefore, that a really fair competitive trial be made between refractors and reflectors, to test their fitness for celestial photography, before any definite decision be arrived at. This need by no means impede or hamper the work of the Congress in deciding other questions which could be made dependent on the results of these trials, and six months would probably decide the question.

In the photographing of nebulæ there can be no doubt whatever as to the superiority of the reflector, for in this case increase of angular aperture means increase of light and reduction of ex-

* Since writing above I have received information, founded on practical results, which materially strengthens my views. Professor Pritchard has succeeded in producing photographs with the De la Rue reflector, in which the images at 80′ from centre are sensibly circular, while at same distance in MM. Henry's (refractor) plates the small star discs are ellipses, the proportion of whose major and minor axes are 9 to 4.

posure, and the angular aperture of reflectors can be increased far beyond what is possible in case of refractors.

In connection with the optical portion of the instrument there are a great number of important points which it would be most desirable to discuss; and I mention some of these, not so much with a view of giving my own individual opinion about them, as in the hope of eliciting opinions from others, and having them fairly and fully discussed.

*Effect of Increase of Actual Aperture.*—Theoretically, so far as star discs are concerned, the brilliancy should increase as the square of the aperture. Long since, in discussing this with Dr. Huggins and Mr. Roberts (before I had any practical results to guide me), I stated that I thought it very likely that the increase of brilliancy would not be in such a high ratio; for practically the discs (of large stars at least) are not mathematical points. Practice, I think, has corroborated this view; but more details are required to make it quite clear.

*Effect of Increase of Angular Aperture.*—The actual aperture remaining the same, reduction of focus or increase of angular aperture ought *not* to increase the brilliancy of star discs; but, for the same reason as above, it would appear that it does so to some considerable extent.

This, however, is also a question that requires more experiments to enable us to come to a decision upon.

*Field of View.*—In a refracting telescope the field of view is limited simply by the amount that can be covered by the objective with sufficiently good definition.

In a reflector the conditions are much more complicated.

If the focus be made long the field is flatter and can be used larger; but, on the other hand, the photographic plate and carrier begin to stop out an inconveniently large portion from the centre of the pencil of light.

If the focus be shortened a smaller plate will take in the same angular quantity of field, but that field will not be so flat.

There appears, therefore, to be some proportion that will be found to be best.

So far as present results go, they tend to show that with either a refractor or reflector a field of about $2° \times 2°$ is the maximum attainable with really good definition. Much larger fields may be obtained with combination of lenses; but these are useless for the purpose, as, the pencils not being *all* centrical, a certain amount of distortion is inevitable.

*Silver-on-Glass or Metallic Mirrors to be used.*—Silver-on-glass mirrors are now so universally used, and so convenient on account of their lightness, that it may seem almost useless to discuss this. However, if the very best result is aimed at, I am inclined to think it might be well to institute some experiments to test the relative reflective powers of speculum-metal and silver for those rays which are used for forming the image on the photographic plate. There are good grounds for supposing that

speculum-metal is more highly reflective for chemical rays than silver.

Long since I obtained photographs of the Moon with the Melbourne telescope, with exposure of from quarter to half a second, using the old collodion process and no peculiarly rapid process. Plates are now made 50 to 100 times as rapid as this old process, but I have never as yet heard of any photographs of the Moon having been taken with a silver-on-glass mirror in $\frac{1}{300}$th or $\frac{1}{400}$th of a second. An idea has been thrown out that the field of a reflector could be improved by modifying the figure of the mirror. This is quite impracticable, as any modification whatever would affect the definition of the central pencil.

It has been objected to reflectors that the film or surface is liable to tarnish, and therefore these instruments are not so stable, and are therefore less suited for long-continued observations.

Metallic mirrors, if the metal is good, I believe to be almost as stable as an object-glass; but even if not so, this is a point of little consequence, for Mr. Roberts tells me that under apparently equal conditions of atmosphere he sometimes obtains three times the number of stars in the same locality as at other times.

With such an enormously variable factor as this to deal with, a slight variation in the condition of the film is of little account.

*Best Size of Instrument to adopt.*—The larger the instrument the shorter the exposure necessary to obtain an image of a star of any given magnitude; but the difference in this respect will probably not (as I have before said) be on as high a ratio as the theoretical—viz. square of aperture.

On the other hand, the larger the instrument the more difficult will it be to find a night sufficiently good to use it advantageously.

The question of size is therefore mixed up with many others, such as geographical position, accuracy of clockwork, minimum magnitude of star desired to be mapped, rapidity of plates, &c.

In order to determine the best size of instrument it would be necessary to determine first the minimum magnitude of star it is desired to photograph; secondly, for what time the clockwork could be depended upon to go sufficiently accurately to preserve the symmetry of the image.

The problem would then resolve itself into this: What is the *least* size of telescope which would photograph that particular magnitude of stars in that particular period with the quickest plates obtainable?

*General Form of the Equatorial Mounting.*—If a reflector be used, and more especially if the mirror be metallic, the ordinary so-called German form of equatorial, slightly modified so as to give circumpolar motion, will fulfil all necessary conditions; but in case of a refractor it has been suggested that the old English split polar axis might be more convenient.

In ordinary eye and micrometrical observations the necessity which exists in all equatorials of the German form of reversal is not any great inconvenience, but in stellar photography absolute circumpolar motion is almost a necessity.

It would not be possible to stop during the exposure of a plate, reverse the telescope. and commence again at the other side. It is possible to make the German form circumpolar in this latitude up to the zenith; but to do so for refractors beyond that involves a construction somewhat of the form of Colonel Tomline's, which is clearly impracticable for instruments which have to be transported.

With a reflector, however, the whole telescope being short, the lower end being short in case of a metallic mirror, and the person of the observer being at the upper end, it is perfectly practicable to make the German form circumpolar—at least for these, and even a lower latitude.

*Effect of Refraction.*—It is very important to study the effect of refraction in disturbing the position of the images; for if, as has been stated, the effect is so great that even in favourable altitudes and with a perfect clock a hand correction must be made every two or three minutes, it would appear almost useless to go to very much trouble about the clock, at least in controlling it so as to keep its rate correct for long periods.

Dr. Dreyer of Armagh has kindly made some calculations for me respecting the effect of refraction. I have only just received his calculations as I send this paper to the printers; but the results are so interesting that they appear worthy of further investigation.

Taking a star near the equator and on the meridian, the difference in Declination for short periods is very small. I have assumed that a shift of star image in plate of $0''\cdot5$ would be the least that could sensibly affect the symmetry of image. That $0''\cdot5$ error would not occur in Declination for nearly half an hour; but in Right Ascension the error would amount to this quantity in two minutes. The curious part, however, is that this difference in Right Ascension is nearly constant for a considerable distance from meridian: thus, one hour off meridian it is still about $0''\cdot5$ in two minutes, and nearly the same at two hours off meridian.

The practical deductions to be drawn from this are:—

(1) That a really perfect controlled clock can be fully utilised, even for long periods, and that it is highly desirable to have such;

(2) That this clock should be provided with an arrangement for introducing very slight changes in its rate.

*Clockwork.*—This is of course the most important of all the details of an equatorial intended to be devoted to stellar photography.

There are many uniform motion clocks which go smoothly and uniformly for short periods; but for long periods it is abso-

FIG. 1.

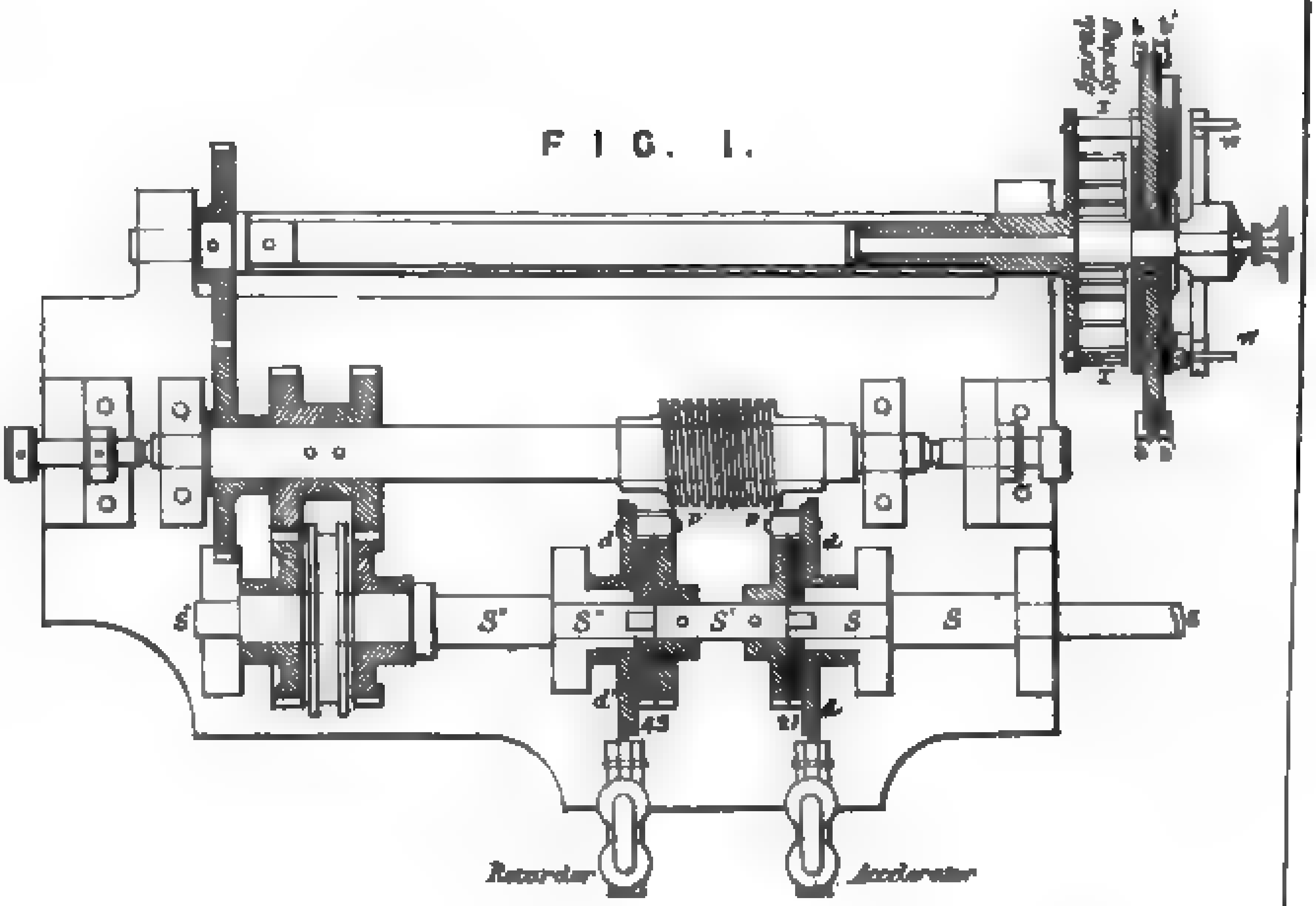



FIG. 2.

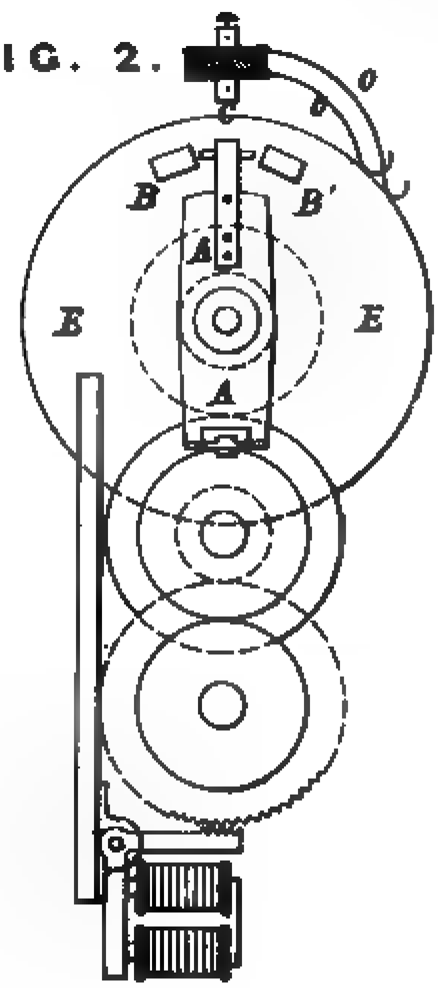
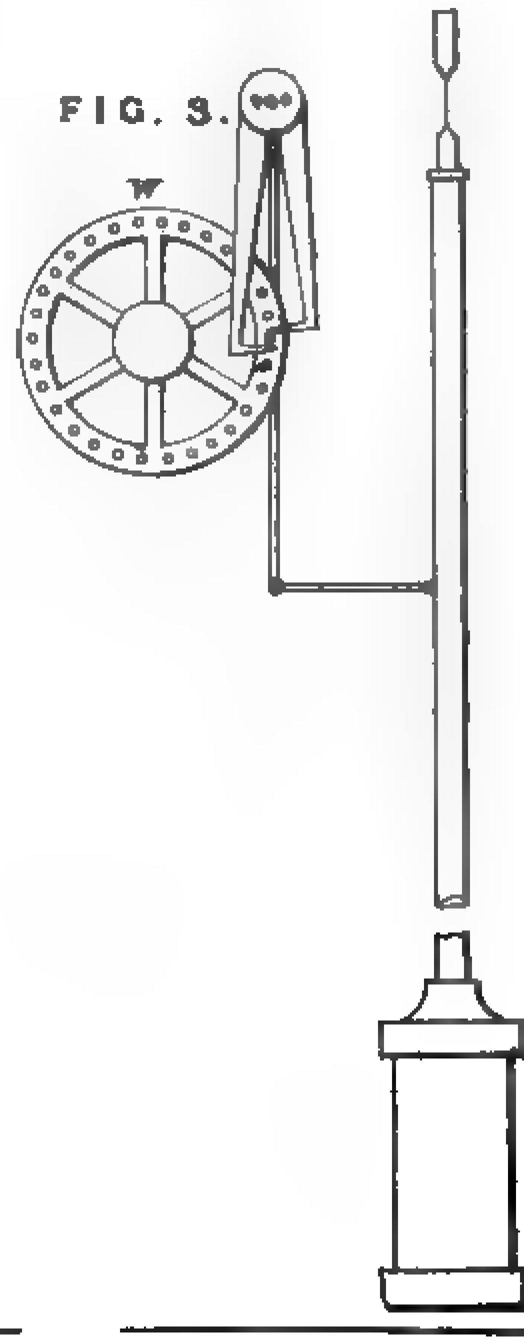



FIG. 3.



lutely necessary to have some controlling action from a pendulum. The form of control which I have found best consists of two parts—

(1) A detector apparatus for detecting the errors of equatorial clock, using as a standard a mercury or other good pendulum driven by a *remontoire*, so as to be uninfluenced by the incorrect rate of the equatorial clock.

(2) A correcting apparatus for correcting any errors found in the equatorial clock by the detector. This corrector itself naturally consists of two parts—an "accelerator" and a "retarder."

It will be necessary to describe first this accelerator and retarder.

Any of the clock-shafts between the clock and the endless screw which drives the Right Ascension sector is cut into three pieces—Plate 4, fig. 1—S, S′, and S″.

On the end of the shaft S is fixed the wheel 1. On the end of the shaft S′, next S, is fixed the wheel 2, close up to and almost touching 1.

On the other end of shaft S′ is fixed the wheel 3, and on nearest end of shaft S″ the wheel 4. Also, on the shafts S and S″ are placed discs of brass, *d* and *d′*, close to the pair of wheels 1-2 and 3-4; but these discs are *free to turn on shafts.*

On a stud on these discs are pinions, *p* and *p′*, which gear across both wheels of each pair, *p* gearing across Nos. 1 and 2, *p′* across Nos. 3 and 4. In general the whole of this apparatus revolves together and as one piece; but it is possible during the action to arrest the motion of one or other of discs *d* and *d′*, which causes the pinion to revolve on its own axis, and the motion is transmitted to the adjacent wheel through the pinion. If the two adjacent wheels have exactly the same number of teeth the speed remains the same; but if one wheel has (say) one tooth more than the other, a slight difference in speed takes place between the driving part and the driven part of the spindle. For example:

Suppose wheel 1 to have 30 teeth and wheel 2 to have 29 teeth, and that spindle S be revolving at the rate of once in 60 seconds. If now the motion of disc *d* be stopped, the wheel No. 2 and its spindle S′ will be revolving once in 58 seconds instead of once in 60 seconds. By reversing the position of the wheels at the other end of spindle S′ a retardation occurs on stopping its disc *d′*.

If, therefore, the normal rate of spindle S, S′, and S″ be once in 60 seconds, a stopping of disc *d* will cause screw to revolve (as long as disc *d* is held) once in 58 seconds, while a stopping of disc *d′* will cause same to revolve once in 62 seconds.

This stopping is actually accomplished by cutting the edge into a set of very fine teeth (see fig. 2) into which a comb or

the armature of an electro-magnet engages. When therefore a current is sent through the magnet of the accelerator the screw is accelerated $\frac{1}{30}$th part, and when sent through the magnet of retarder the screw is retarded $\frac{1}{30}$th part.

To understand how these currents are sent from the detector, see figs. 2 and 3.

A scape-wheel, W, is mounted on a 60-second spindle of clock, and driven from that spindle by a spiral spring $x$ $x$, fig. 1, so that no error of equatorial clock can affect its rate or the rate of the pendulum. On same clock-spindle behind scape-wheel is mounted an ebonite disc, E E, fig. 2, on which are fixed two brass insulated rings, $b$ $b$, fig. 1, connected metallically with two platinum plates B B′, inserted in face of ebonite disc E E.

Between scape-wheel and ebonite disc is an arm, A A, also mounted on spindle and loose on it, having at its end a little platinum bridge C, of such a length as to fit between the two platinum plates B and B′.

The ebonite disc moves uniformly with the equatorial clock.

The scape-wheel works absolutely correctly with the pendulum and is uninfluenced by error in clock.

The arm A A moves by friction from the ebonite disc, and remains with its bridge exactly between the two platinum discs B and B′ so long as the rate of clock is exactly coincident with the rate of scape-wheel; but if the clock goes the least faster or slower, a pin on the scape-wheel touches arm A, moves bridge C into contact with B or B′, and sends a current through the accelerator or retarder until that error be corrected.

A piece of rock-crystal is inserted between the two pieces of platinum for the bridge to slide on.

The current is guided to brass rings $b$ $b'$ by the fine platinum wires $o$ $o'$, which wipe against them.

The time which the accelerator or retarder is kept in action depends on the amount of error it is necessary to correct.

Assuming the proportions given above for teeth of wheels, and that an error—of, say, $\frac{1}{5}$th of a second—is by some means introduced, the corrector will be held in contact for 6 seconds, because for every revolution it is held in contact (that is, for every 60 seconds) a correction of 2 seconds will be made, so 6 seconds' contact will correct $\frac{1}{5}$th of a second.

The advantages of this control are—

(1) It not only brings the rate of the clock right after any temporary disturbance, but it *corrects* any errors that may have already occurred. This is absolutely necessary for photographic work, as otherwise the star would occupy a new position on the plate though rate of clock were corrected. [N.B.—all ordinary forms of fan, frictional governor, isochronous pendulum, &c., only tend to correct the *rate* of the clock, but do not deal with any error already existing.]

(2) The detector arrangement. being attached close to screw-spindle, takes cognisance of all the errors of the various spindles and wheels between clock and screw as well as clock itself.

(3) It is more smooth and equable in its action than any other form, for instead of endeavouring to alter the rate of a heavy moving governor *it allows it to go wrong*; but introduces a corrective arrangement into the gearing so as to *compel the screw* to revolve exactly correctly.

The practical result of this control-clock I find to be that it is admirable for long periods; but the delicacy of the detector part is not as great as I could desire.

Owing to the fact that the linear measure of a second of time on the detector disc (revolving once in 60 seconds) is a small quantity, I find that practically the detector will not detect errors less than $\frac{1}{8}$th to $\frac{1}{10}$th of a second; but it will keep the clock right within *that* error for any number of hours. In other words, the correcting portion of the apparatus (the accelerator and retarder) work perfectly, but the detector is not quite delicate enough. I think it likely that a combination of Dr. Gill's detector (that used at Dun Echt) and my corrector would give the most perfect clock-control possible.

I prefer my corrector because it takes into its influence all the errors of the various connecting shafts, &c., between clock and sector, which Dr. Gill's does not.

Dr. Gill has suggested, in order to avoid all unnecessary wheels and gearing between governors and screw, that the governor spindle should have an endless screw cut on it, gearing *directly* into a toothed wheel on screw-spindle, and that this governor should be driven by a small electric motor and governed from the control by a variable resistance apparatus. The first part of this I consider a most admirable suggestion; but instead of driving by electricity and regulating by the varying resistance, I would still drive by a weight and introduce the correction by my accelerator and retarder, which I find to work so well.

There are many reasons for which I prefer this to the electric driving, among which are:—

(*a*) That whenever possible I prefer gravity (which never fails us) to batteries, as a motive power.

(*b*) That when we apply a corrector which necessitates the alteration of speed of a heavy and quick-moving mass (such as the governor) we are apt to set up a slight swing in the motion. The accelerator and retarder above described are free from that defect.

(*c*) If we adopt the electric driver, the control would have to correct all the errors due to want of constancy of

the battery as well as the mechanical errors of the clock, and as the former would probably amount to 20 per cent. of the whole, while the latter need not exceed $\frac{1}{3}$rd per cent., it is evident that $\frac{59}{60}$ths of the work of the control would be used in correcting a factor (the driving power) which, by adopting gravity, we render practically constant.

The form, therefore, of clockwork I would recommend as probably the best at present possible would be one driven by a weight, the governor gearing directly into a wheel or screw shaft. A *detector* similar to Dr. Gill's at Dun Echt, but driven, not from clock, but directly from screw-spindle, with only one pair of wheels intervening, and a pair of *correctors* on the principle of my accelerator and retarder.

*Slow Motion of Equatorial.*—For stellar photography it is absolutely necessary to have a slow motion of far greater delicacy and precision than that which suffices for micrometrical work. If in micrometrical work a slight turn of the handle to bring the star central causes the telescope to oscillate very slightly it is of no consequence, as the eye can wait till the oscillation subsides (I am speaking, of course, of extremely small quantities); but in an instrument for stellar photography this is not admissible, as it would cause the star disc to be elongated. Special arrangements, therefore, must be made for the slow motion in the photographic telescope.

*Slow Motion in Right Ascension.*—For this purpose (beside the ordinary slow motion used to bring star to centre of field) I find the best arrangement is to have another accelerator and retarder, similar to those described above for clock control, and to have the electro-magnets of these connected to a little commutator with two keys held in the hand of the observer. By pressing one the clock-spindle is caused to revolve $\frac{1}{30}$th part faster, and continues at this faster speed so long as the key is held down. By pressing the other a corresponding retardation occurs.

By using this arrangement there is no possibility of causing any jerk or sudden movement in the instrument. The key is held in the hand and is totally independent of the instrument. Pressing the key simply causes the screw to revolve $\frac{1}{30}$th part faster or slower for the time being.

*Slow Motion in Declination.*—I would be glad if possible to have an equally perfect arrangement for the Declination slow motion; but I do not see how this can be accomplished; and, fortunately, it is not quite so important as it is not so often in use. I incline to think that the German form of slow motion—i.e. a fine screw acting against a stiff spring—would be the best form, only that the strength of the spring is not constant, and, unless made very stiff, does not work well. I have introduced a modification of this which removes these objections.

A B C D (fig. 4) is a portion of the arm attached to telescope

or cradle, on which is planted the block ($b$) forming the bearing of the screw. The nut ($n$) is in the form of a ball, working in a socket on the extremity of the clamp-arm E F G. A short stiff spring (S) is attached to this clamp-arm, bearing not directly against any part of other arm, but against end of a *second screw of same pitch as the main screw*, the nut of which ($o\,o$) is toothed on edge and works into a wheel of equal size ($p\,p$) on main screw. The point of this second screw, therefore, advances as much in one direction as the frame A B C D is carried in the other, according as the milled head is turned; and consequently the point of the screw does not sensibly vary in its position with respect to the clamp arm E F G. A short stiff spring can therefore be used, and the disadvantage above mentioned disappears.

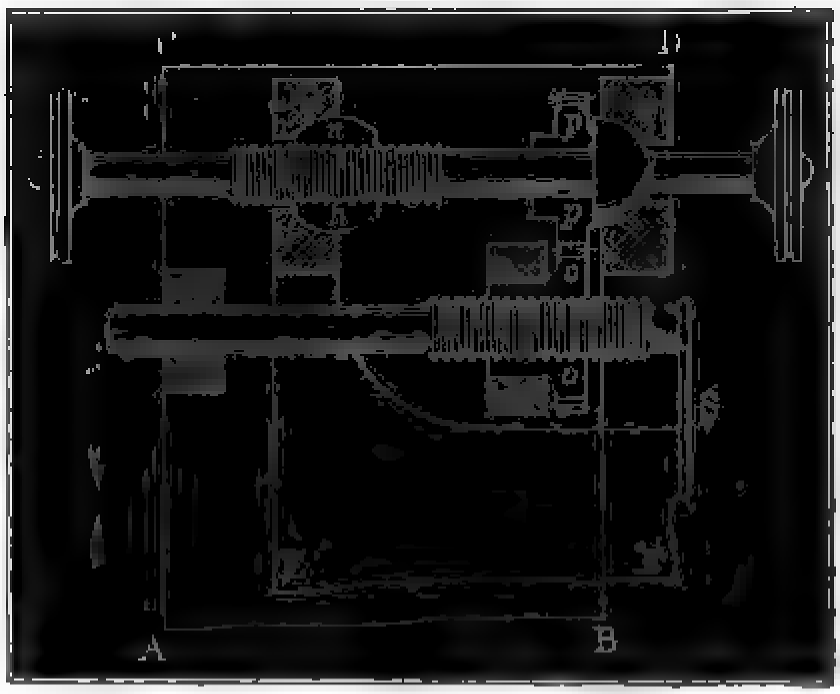



Fig. 4.

The most serious difficulty in using reflectors appears to be that of the want of constancy of the axis of collimation. A mirror cannot be fixed into its cell with the same rigidity as is possible in case of an object-glass, and if the smallest shift occurs during the exposure, any attempt to make the clock drive correctly or to keep a star on cross-line of finder by laborious eye observations are utterly futile.

The shorter the exposure, of course, the less danger of any shift during an exposure; but some system must be devised by which the axis of the finder can be kept in a constant position not as regards the tube or mechanical fixtures of the reflector, but as respects its true optical axis.

This is not a very simple problem, but I feel quite sure that it is quite capable of being solved.

The necessity of its solution did not arise till now, and therefore no attention has been given to it.

Let it be remembered that we have three possible sources of error—

(1) Lateral shift of mirror, i.e. sliding bodily on its supports.
(2) Flexure of tube.
(3) Tilting of mirror.

By giving the back of the mirror a convex curve equal in radius to concave at front + thickness of disc, the lateral shift has no effect on the collimation. The other two, however, have a very serious effect. An arrangement such as the following would take into account the error in collimation produced by either or both these.

Fig. 5.

Beside, and a little behind, the photographic plate, *but attached* to same supports, let there be a small electric lamp, *e*, enclosed in a little box, and having in front a silvered glass window on which is scratched a minute circle Let a prism and lens, *p*, be mounted

on large mirror itself, in such position as to form an image of that little illuminated circle at *i*. Let the finder telescope be provided near eye-end with a diagonal mirror, *a a*, having a hole in centre, so that the image is thrown out to side of its tube at *i*; and let a lens be mounted in centre hole of that mirror, which will re-form the image of circle at *i'*. On looking into field of finder a ghost image of this circle will be seen in field, and the position of this ghost in field of finder will be affected by flexure of the tube of great telescope or tilting of great mirror. Therefore, if instead of keeping any certain star on fixed cross-lines of finder it be kept in *centre of this ghost ring*, the optical axes of finder and reflector will be kept constant, and the image on photo-plate will be absolutely steady, provided any star in field of finder be kept constantly in centre of that ghost circle.

It is quite possible that a better arrangement than this will be devised; but I mention the first that occurs to me in order to show that it is at least possible.*

*Curved Plates.*—It appears quite possible that the adoption of slightly curved plates might add considerably to the possible amount of field to be photographed with sufficient sharpness.

The curvature necessary to place the lateral portions of the plate in the place of least confusion would be very slight. In the case, say, of a reflector of 10 feet focus and for a field of 2° the versed sine of this curve would only be about $\frac{1}{80}$th of an inch.

There could be no manipulatory difficulties in coating a plate of this curve, for the common plates in ordinary use by photographers have often more curvature (accidentally) than this.

There would be no danger of any distortion occurring in reducing the observations from these plates if proper precautions were taken, and any extra expense of plates would be more than compensated for if even $\frac{1}{2}$° of additional field could be obtained with the same distinctness.

Many other points beside those above mentioned will have to be considered and discussed before it is possible to come to a definite conclusion as to the best instrumental equipment for stellar photography; but the object of this paper will have been attained if I have succeeded in showing that the subject is one in which new and unexpected conditions are continually presented for our consideration; and, that while we know enough now to be able to say that a certain instrument will give a good result, we really have not as yet sufficient data to enable us to say what will be likely to give the *best* result. For instance, the different conditions, instrumental and otherwise, under which Mr. Roberts and the MM. Henry have been working preclude any idea of drawing a decisive conclusion from a comparison of their results.

It appears to me that the most useful work the Paris Congress

* It may be observed that fig. 5 is only a diagram, and that the comparative size of the various parts of this collimating apparatus, as compared to telescope, are very much exaggerated for clearness' sake.

could do would be to formulate a series of experiments which would clear up all debatable points. Arrangements might also be made to enable the work to be carried on immediately after these experiments were completed, the general features of the instrumental equipment to be contingent upon the result of the experiments. If it be possible for me to take advantage of the kind invitation of the French Astronomers, this is the view which I propose to put forward at the Congress.

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## *Remarks on some of the present Aspects of Celestial Photography.* By Professor C. Pritchard, D.D., F.R.S.

When a new science, or a new application of an old one, is in the early stages of its development, as is now the case with stellar photography, any practical remarks connected with its history and progress will certainly possess a peculiar interest when, in the distant future, the art shall have been brought to comparative perfection. It is under this view that I venture to occupy for a few minutes the attention of the Society.

We are greatly indebted to General Tennant for his recent contribution to our theoretical knowledge of the nature and position of the foci of cylindrical pencils of light incident on parabolic mirrors, when the axes of these pencils are inclined to each other at considerable angles. By considerable angles I mean such as extend through one to three, or even four, degrees. These investigations have a very close and important bearing on questions relating to the angular extent of the photographic pictures of the heavens, which may be hoped for through the instrumentality of reflecting telescopes. One result which I gather from General Tennant's labour is that, even at angles slightly exceeding one degree from the axis of the mirror, discernible astigmatism and distortion may be expected to commence; and if such be found to be the actual result in practice, then photographic pictures of the distribution of stars will be necessarily confined within very narrow limits indeed; and if the whole heavens are to be photographically charted, then the number of the plates will become unavoidably enormous, inasmuch as no single plate could be expected to contain more than five or six square degrees, in at all events such perfection as not to offend the eye, and remind it forcibly and continuously of the comparative imperfection of the means adopted for the formation of the pictures. Passing for a moment from these inauspicious expectations of aid from telescopic mirrors, I find from a recent printed note of Mr. Common that the photographic results, at present derived from specially constructed object-glasses, are, in respect of accuracy of form and extent of available field, not much more hopeful than those predicted by mathematical in-

vestigation in the case of reflectors. Mr. Common, speaking of the really beautiful results obtained by MM. Henry, says: "Looking now at a picture of one of the faintest stars on the plate, and about the centre of the field, these images are quite distinct and perfectly symmetrical; it is only when we get about 1° from the centre that distortion begins. . . . We must therefore consider that the field of this instrument is a circle of about 2° diameter . . ."

It was with a view of ascertaining, in respect of circularity of the stellar images and available extent of the field, *within the limits of agreeable representation*, that I recently commenced some experiments with the De la Rue reflecting telescope of 13 inches aperture. The ordinary plate-holder of this instrument is a circle of two inches only in diameter, at a focal distance of 120 inches, and consequently it comprehends a field scarcely exceeding a single degree in diameter. Beautifully perfect as this field is, and presenting images of the fainter stars admitting of refined measurements, suitable even for the purposes of stellar parallax, it affords no adequate extent of picture practically adapted for the larger scheme of charting the heavens. I accordingly caused to be constructed a camera of more than double this diameter, and affording a circular field extending to about 2°·7; and although its construction with home resources was very rough and temporary in its character, nevertheless a series of negatives was obtained exhibiting not the slightest discernible deformity in the figures of the stars. This encourages me to hope that the field may be safely extended yet further with suitable appliances, and possibly sufficiently so for efficient and general charting. One of these negatives thus considerably passing the angular limits indicated by the mathematical analysis, I have very recently submitted to the judgment of some members of the committee delegated by the Society to inquire into such matters.

Independently of this, at a meeting of the Photographic Committee of the Royal Society, comprising several of the members of the former body, it was proposed that experiments should be made with two mirrors of widely different focal lengths in order to determine what is the greatest extent of available field to which photographic pictures can be thereby carried. Mr. De la Rue, with his well-known and thoughtful generosity, undertook to provide two such mirrors for the determination of the question, and he has placed them in my hands at Oxford with the view of mounting them temporarily on the solid frame of his reflector in the University Observatory. The aperture of each is 15 inches, with focal lengths respectively of 80 inches and 120 inches. Cameras are now in process of construction capable of photographing fields of 3° 20′, and extending to nearly 5° in diameter. What the result may be cannot be told until after the inquiry has been completed.

There is also another question of some importance to be

decided. It relates to the conical or trumpet-shaped form of the telescope tube, indicated in General Tennant's paper already referred to. There can be no doubt that owing to the ordinary cylindrical form of the tube very much light from stars whose images are formed near the edge of the field is cut off from incidence on the mirror. This fact will also necessarily interfere with the correct estimation of the magnitude of such stars. On the other hand, it is indicated in the analysis referred to that there is much probability of astigmatism and distortion in the images of these widely angular pencils, and it may even turn out that deformation is partially prevented by the mouth of the ordinary cylindrical tube; for it is one of the results of the mathematical investigation that a diaphragm placed within the tube may conduce in some degree to the flatness of the field. All this is a subject for further practical inquiry, and, as Mr. Common reminds us by a forcible remark, "there is not (at present) much information available, and what there is is such as rather raises than removes doubts."

Should it so happen that considerably wider fields than those indicated by the mathematical analysis can be successfully pictured on the plates, this need not be regarded as contravening the correct interpretation of General Tennant's research. For the photographic images are not in any sense mathematical points; and as to their physical genesis, we are greatly in the dark. One thing is certain, that they grow under continuous exposure; but whether that growth is due to the diffusion of the light, or in some degree to the unsteadiness of the atmosphere or of the instrument, or to some molecular action, extending as it were from a centre of disturbance, who can at present tell?

One conclusion, I think, is clearly deducible from the foregoing remarks, to the effect that the method and final plan of a general charting of the heavens is not yet wholly ripe for decision. For my own part, I do not think it a chimerical hope that before long it may be within the power of a single observatory, provided with two, or it may be three, capable assistants, to procure a series of charts of the heavens, extending from the Pole to the Equator, photographed on an efficient scale, without unpleasant distortion, extending to stars nearly as faint as the fifteenth magnitude, and reproduced in a permanent form nearly to the fourteenth, and then circulated among astronomers within a space of time not exceeding four years. The plates, however, must necessarily be duplicated by a second instrument for the purposes of rectification.

These, however, are questions which await discussion at the approaching Conference at Paris. Meanwhile there are two mottoes applicable to the present condition of the matter before us. The one is "*Forwards!*" and the other is "*Festina Lente.*"

1887, *April* 5.

*On the Variations of Level and Azimuth of the Transit Circle at the Royal Observatory, Greenwich.* By H. H. Turner, M.A., B.Sc.

In Vol. XXIX. of the *Memoirs* of the Royal Astronomical Society, Mr. William Ellis has given a very complete account of the changes of level and azimuth errors of the Transit Circle during the early years of its history (1851–1858). He found that there were fluctuations in the position of the instrument in both these elements which followed very closely the changes of external temperature, especially those of long period, such as the annual variation. As the changes of position of an instrument which has been in constant use for so long a period are of interest, the following tables have been recently formed, showing the simple arithmetical mean of the adopted level errors in each month, and of the adopted azimuth errors in each month, for the period 1851–1884. From the means for each month that for the year has been formed (in the column on the right); and similarly the means for the separate months have been formed (in the bottom line), excluding those years in which the changes mentioned in the notes have been made.

*Mean Values of Adopted Level Error of the Transit Circle for each month and for each year since its erection.*

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | " | " | " | " | " | " | " | " | " | " | " | " | " |
| 1851 | − 2·64 | − 3·38 | − 4·01 | −4·53 | −4·83 | −5·91 | −4·56 | − 4·31 | − 2·71 | − 1·75 | − 0·61 | − 1·49 | − 3·39 |
| 1852 | − 2·20 | − 2·72 | − 2·79 | −3·14 | −3·99 | −4·61 | −6·12 | − 2·64 | − 0·52 | − 0·43 | − 1·29 | − 1·23 | − 2·64 |
| 1853 | − 1·37 | − 1·07 | − 1·75 | −2·56 | −3·51 | −3·38 | −2·92 | − 1·60 | − 0·30 | 0·00 | + 0·63 | + 0·86 | − 1·41 |
| 1854 | − 1·38 | − 1·44 | − 1·72 | −2·42 | −1·79 | −2·50 | −2·83 | − 1·46 | − 0·31 | + 1·75 | + 2·59 | + 2·06 | − 0·79 |
| 1855 | + 1·43 | + 1·70 | + 0·95 | −0·02 | −0·72 | −0·81 | −0·85 | + 0·09 | + 1·94 | + 2·93 | + 3·52 | + 2·47 | + 1·05 |
| 1856 | + 2·22 | + 1·78 | + 1·77 | +0·12 | −0·10 | −0·73 | −0·70 | + 0·29 | + 2·25 | + 3·13 | + 3·78 | + 3·15 | + 1·41 |
| 1857 | + 2·70 | + 2·07 | + 1·61 | +0·82 | −0·13 | −0·92 | +0·59 | + 1·77 | + 3·49 | + 4·84 | + 5·59 | + 4·66 | + 2·26 |
| 1858 | + 4·18 | + 4·16 | + 2·73 | +1·70 | +1·50 | +0·02 | +2·32 | + 3·43 | + 4·29 | + 5·61 | + 5·62 | + 4·96 | + 3·38 |
| 1859 | + 5·00 | + 4·20 | + 3·57 | +3·49 | +3·17 | +1·58 | +1·89 | + 4·71 | + 6·63 | + 7·39 | + 7·40 | + 6·95 | + 4·66 |
| 1860 | + 6·37 | + 5·81 | + 5·08 | +4·42 | +2·86 | +3·44 | +3·37 | + 4·22 | + 5·42 | + 5·85 | + 6·79 | + 6·33 | + 5·00 |
| 1861 | + 5·87 | + 4·94 | + 4·60 | +5·58 | +3·71 | +3·16 | +4·70 | + 5·11 | + 7·03 | + 7·23 | + 8·44 | + 7·63 | + 5·67 |
| 1862 | + 6·93 | + 6·48 | + 5·11 | +4·79 | +3·20 | +3·72 | +3·99 | + 4·89 | + 6·02 | + 7·16 | + 8·01 | + 7·34 | + 5·64 |
| 1863 | + 6·87 | + 7·17 | + 6·38 | +5·65 | +4·86 | +4·87 | +5·98 | + 6·18 | + 8·45 | + 8·29 | + 8·84 | + 8·68 | + 6·85 |
| 1864 | + 8·29 | + 8·09 | + 7·39 | +4·76 | +5·66 | +6·17 | +6·36 | + 7·66 | + 9·08 | + 9·61 | +10·05 | +10·07 | + 7·77 |
| 1865 | + 9·79 | + 8·90 | + 8·61 | +6·33 | +6·16 | +6·67 | +7·09 | + 9·26 | + 9·10 | +10·97 | +11·30 | +10·95 | + 8·76 |
| 1866 | +10·59 | + 9·88 | + 9·72 | +8·32 | +8·67 | +7·35 | +8·42 | + 9·25 | +10·65 | +10·79 | +10·92 | +10·98 | + 9·63 |
| 1867 | +10·43 | + 9·63 | + 9·91 | +7·90 | +6·94 | +7·05 | +7·84 | + 7·32 | + 9·43 | +12·79 | +10·72 | +10·36 | + 9·19 |

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | " | " | " | " | " | " | " | " | " | " | " | " | " |
| 1868 | + 9·41 | + 8·57 | + 8·31 | +7·46 | +6·26 | +6·37 | +7·06 | +10·15 | +10·78 | +12·44 | +12·61 | +11·51 | + 9·24 |
| 1869 | +11·57 | +10·23 | +10·74 | +8·02 | +9·02 | +8·28 | +7·31 | + 9·45 | + 9·98 | +11·89 | +11·90 | +11·82 | +10·02 |
| 1870(*a*) | +10·91 | +10·69 | + 9·60 | +8·49 | +7·82 | +7·61 | +7·94 | +10·41 | +10·88 | +11·39 | ... | + 2·77 | ... |
| 1871 | + 2·30 | + 0·49 | + 0·08 | −0·07 | −0·70 | −0·29 | −1·34 | − 1·01 | − 1·65 | + 2·95 | + 2·99 | + 2·27 | + 1·11 |
| 1872 | + 1·84 | + 0·98 | + 0·88 | −0·49 | −0·68 | −2·31 | −1·67 | + 0·65 | + 1·53 | + 2·88 | + 1·83 | + 2·40 | + 0·65 |
| 1873 | + 1·39 | + 1·13 | + 0·09 | −0·17 | −1·20 | −2·32 | −2·45 | − 0·63 | + 1·38 | + 2·44 | + 1·82 | + 1·72 | + 0·27 |
| 1874 | + 1·15 | + 1·19 | − 0·24 | −1·74 | −0·33 | −1·54 | −1·85 | − 0·21 | + 0·69 | + 1·73 | + 2·51 | + 2·41 | + 0·31 |
| 1875 | + 0·43 | + 0·67 | − 0·37 | −0·95 | −2·53 | −2·46 | −1·94 | − 2·41 | − 0·69 | + 0·70 | + 0·96 | + 0·25 | − 0·69 |
| 1876 | − 0·46 | − 1·25 | − 0·89 | −1·57 | −2·10 | −3·99 | −3·95 | − 2·29 | + 0·08 | + 0·03 | + 0·68 | − 0·07 | − 1·31 |
| 1877(*b*) | − 1·23 | − 1·86 | − 2·29 | −3·09 | −3·53 | −5·76 | −4·48 | − 3·92 | − 1·56 | − 1·46 | − 1·00 | (− 1·03) | − 2·60 |
| 1878 | − 1·85 | − 3·08 | − 2·40 | −3·68 | −4·45 | −6·29 | −5·47 | − 3·84 | − 2·27 | − 1·82 | − 1·18 | − 1·70 | − 3·17 |
| 1879 | − 2·41 | − 3·92 | − 4·16 | −4·64 | −5·05 | −5·47 | −6·62 | − 6·61 | − 5·05 | − 3·95 | − 3·07 | − 3·12 | − 4·51 |
| 1880 | − 4·62 | − 5·52 | − 5·85 | −6·33 | −7·46 | −7·98 | −8·42 | − 7·76 | − 5·76 | − 4·08 | − 3·76 | − 5·04 | − 6·05 |
| 1881(*c*) | − 4·46 | − 5·37 | − 6·34 | −7·39 | −8·49 | −8·53 | ... | − 0·75 | + 0·51 | + 1·81 | + 0·87 | + 0·93 | ... |
| 1882 | + 0·44 | − 0·22 | − 2·48 | −2·12 | −3·22 | −3·31 | −2·24 | − 1·39 | + 0·02 | + 0·85 | + 0·88 | + 0·23 | − 1·03 |
| 1883 | − 0·59 | − 1·37 | − 1·18 | −2·84 | −3·20 | −3·61 | −3·49 | − 2·77 | − 1·26 | − 0·13 | − 0·06 | − 0·05 | − 1·71 |
| 1884 | − 1·34 | − 1·50 | − 2·92 | −2·46 | −3·72 | −3·96 | −4·42 | − 3·97 | − 1·93 | − 0·66 | − 0·61 | − 1·22 | − 2·39 |
| Mean | + 2·91 | + 2·34 | + 1·83 | +0·96 | +0·40 | −0·12 | +0·16 | + 1·34 | + 2·87 | + 3·92 | + 4·19 | + 3·75 | + 2·05 |

*Mean Values of Adopted Azimuth Error of the Transit Circle for each month and for each year since its erection.*

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ″ |
| 1851 | −7·13 | −8·29 | −7·28 | −6·72 | −6·12 | −3·19 | −1·61 | − 0·72 | + 0·02 | − 1·21 | −3·97 | −5·62 | −4·32 |
| 1852 | −6·54 | −7·96 | −8·45 | −7·82 | −7·57 | −6·00 | −2·77 | − 1·32 | − 0·36 | − 1·32 | −2·70 | −3·40 | −4·68 |
| 1853 | −4·28 | −7·68 | −9·09 | −9·82 | −6·63 | −4·79 | −2·35 | − 0·84 | − 0·57 | − 0·87 | −3·46 | −6·05 | −4·70 |
| 1854 | −7·89 | −9·34 | −7·44 | −8·16 | −7·04 | −5·47 | −3·57 | − 2·74 | − 2·07 | − 2·39 | −3·02 | −5·12 | −5·35 |
| 1855 | −7·70 | −9·25 | −9·45 | −7·69 | −7·59 | −4·59 | −2·59 | − 1·03 | − 0·68 | + 0·32 | −1·67 | −5·09 | −4·75 |
| 1856 | −5·76 | −7·28 | −7·61 | −6·53 | −6·21 | −2·87 | −1·40 | + 1·05 | + 0·18 | + 0·49 | −3·21 | −3·12 | −3·52 |
| 1857 | −5·34 | −6·19 | −6·61 | −5·42 | −3·75 | −1·96 | +0·31 | + 2·43 | + 3·34 | + 2·39 | +0·62 | −0·61 | −1·73 |
| 1858 | −3·02 | −5·55 | −7·08 | −6·30 | −4·46 | −0·90 | +0·16 | + 1·85 | + 1·96 | + 0·65 | −1·35 | −1·54 | −2·13 |
| 1859 | −3·37 | −3·97 | −4·99 | −5·36 | −4·32 | −1·57 | +2·47 | + 4·03 | + 3·75 | + 2·73 | −0·18 | −1·72 | −1·04 |
| 1860 | −2·78 | −5·27 | −5·60 | −7·12 | −4·60 | −3·55 | −2·53 | − 0·59 | − 1·02 | − 1·54 | −2·81 | −3·95 | −3·45 |
| 1861 | −6·89 | −6·71 | −7·19 | −6·11 | −7·31 | −4·16 | −1·43 | + 0·77 | + 0·65 | + 0·55 | −2·11 | −3·65 | −3·63 |
| 1862 | −5·31 | −4·21 | −5·86 | −4·80 | −3·44 | −2·51 | −0·68 | + 0·26 | + 0·76 | + 0·01 | −2·60 | −3·19 | −2·63 |
| 1863 | −5·22 | −4·14 | −6·01 | −5·45 | −5·02 | −1·93 | +0·95 | + 1·52 | + 0·57 | + 0·43 | −1·30 | −3·26 | −2·41 |
| 1864 | −6·33 | −5·75 | −7·01 | −5·77 | −3·30 | −2·33 | −0·46 | + 1·51 | + 1·85 | − 0·28 | −2·47 | −2·93 | −2·77 |
| 1865 | −5·29 | −6·45 | −7·67 | −4·92 | −3·66 | −0·85 | +1·23 | + 1·73 | + 4·15 | + 0·59 | −0·92 | −1·42 | −1·96 |
| 1866 | −2·27 | −4·27 | −5·08 | −3·41 | −3·34 | +0·50 | +2·46 | + 2·25 | + 2·66 | + 1·13 | −1·19 | −0·80 | −0·95 |
| 1867 | −3·94 | −1·87 | −3·35 | −2·49 | −1·69 | +0·73 | +0·45 | + 3·23 | + 4·06 | + 0·72 | −1·28 | −3·84 | −0·77 |
| 1868 | −5·58 | −5·00 | −5·19 | −4·92 | −2·71 | +0·32 | +3·22 | + 4·21 | + 3·55 | + 3·09 | +0·30 | +0·54 | −0·68 |
| 1869 | −2·56 | −2·10 | −4·62 | −3·47 | −2·08 | −0·94 | +2·57 | + 3·14 | + 3·35 | + 2·50 | −0·67 | −2·36 | −0·60 |
| 1870 | −3·97 | −5·60 | −5·93 | −4·87 | −2·74 | +0·66 | +2·59 | + 3·54 | + 2·50 | + 1·89 | {−0·35 / −1·11} (a) | −3·38 | −1·34 |

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Mean. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | " | " | " | " | " | " | " | " | " | " | " | " | " |
| 1871 | −5.48 | −4.18 | −4.09 | −3.96 | −3.25 | −1.20 | +1.05 | + 3.41 | + 4.09 | + 2.18 | −0.94 | −2.96 | −1.28 |
| 1872 | −2.30 | −2.41 | −2.59 | −1.90 | −1.96 | +0.07 | +2.77 | + 4.92 | + 4.66 | + 2.34 | +1.24 | −0.16 | +0.39 |
| 1873 | −0.82 | −3.72 | −3.11 | −1.61 | −1.38 | +0.10 | +3.44 | + 4.89 | + 3.84 | + 2.68 | −0.16 | −0.89 | +0.27 |
| 1874 | −0.33 | −1.72 | −1.01 | −0.04 | +0.77 | +3.31 | +5.36 | + 5.36 | + 5.88 | + 4.37 | +2.52 | −0.56 | +1.99 |
| 1875 | −0.65 | −1.08 | −1.64 | −0.31 | +2.08 | +4.65 | +6.42 | + 8.78 | + 9.33 | + 8.09 | +5.27 | +2.87 | +3.65 |
| 1876 | +1.95 | +1.91 | +2.18 | +2.97 | +3.32 | +5.68 | +9.19 | +10.79 | + 9.45 | + 9.16 | +6.76 | +6.66 | +5.83 |
| 1877 | +5.77 | +4.93 | +3.44 | +3.67 | +4.05 | +7.38 | +8.92 | +11.19 | +10.60 | + 9.43 | +8.45 | {−1.72 / +5.97} (b) | +6.35 |
| 1878 | −2.95 | −2.61 | −1.86 | −2.09 | −0.23 | +0.06 | +3.44 | + 5.30 | + 4.91 | + 4.54 | +0.49 | −1.97 | +0.59 |
| 1879 | −2.93 | −2.96 | −1.70 | −2.59 | −1.14 | +1.59 | +2.54 | + 4.75 | + 4.83 | + 4.38 | +1.40 | −1.93 | +0.52 |
| 1880 | −3.09 | −1.94 | −0.31 | −0.23 | +1.06 | +2.13 | +4.47 | + 5.61 | + 7.27 | + 4.85 | +2.07 | +1.62 | +1.96 |
| 1881 | −1.93 | −1.40 | −0.83 | −1.25 | +0.63 | +2.83 | +5.79 | (+ 8.16)(c) | + 7.80 | + 6.11 | +5.82 | +4.47 | (+3.02) |
| 1882 | +3.62 | +3.35 | +2.96 | +3.39 | +5.30 | +6.15 | +8.36 | + 9.59 | + 9.26 | + 8.70 | +6.44 | +4.68 | +5.98 |
| 1883 | +3.47 | +2.91 | +0.84 | +1.63 | +4.38 | +6.48 | +7.06 | + 9.64 | +10.07 | + 9.11 | +6.74 | +5.93 | +5.69 |
| 1884 | +5.43 | +4.56 | +4.61 | +4.45 | +6.00 | +7.86 | +8.91 | +10.99 | +11.23 | +10.59 | +9.29 | +8.17 | +7.67 |
| | −3.27 | −3.84 | −4.20 | −3.63 | −2.45 | −0.30 | +1.85 | + 3.38 | + 3.58 | + 2.55 | +0.23 | −0.96 | Mean |

*Notes.*

(*a*) 1870, Nov. 19.—Eastern Y raised and sheet of thin paper placed under it. The Y was adjusted in azimuth by means of the collimators. The two numbers given for azimuth are the means for the two portions of the month.

(*b*) 1877, Dec. 4.—Western Y moved slightly to N to reduce azimuth error. The upper number for azimuth is the actual monthly mean. The lower has been formed by differencing from 1876 and 1878, for use in the annual variation.

(*c*) 1881, July 27–29.—Eastern Y raised and sheet of paper removed. Y adjusted in azimuth by reference to collimators.

The last columns exhibit the secular change in the position of the instrument. The lowest lines exhibit, after correction for that part of the secular change which takes place throughout the year, the annual variation. I have thought it of interest to express this variation in harmonics of annual and semi-annual period, giving at the same time the corresponding expression for the temperature of the air, whose connection with these fluctuations Mr. Ellis has already pointed out. The results are as follows—the unit of time being one year, and the months being assumed of equal length:—

| | |
|---|---|
| Level | $-1''\cdot96 \sin(298^\circ\ 45' + t.\,360^\circ) - 0''\cdot45 \sin(67^\circ\ 55' + 2t.\,360^\circ)$. |
| Azimuth | $+3''\cdot75 \sin(204\ \ 7 + t.\,360) + 0''\cdot44 \sin(341\ \ 30 + 2t.\,360)$. |
| Temperature | $12^\circ\cdot22 \sin(247\ \ 13 + t.\,360) + 1^\circ\cdot23 \sin(30\ \ 42 + 2t.\,360)$. |

I have only given two terms of the harmonic series, although the residuals of the means of so many years show traces of being capable of further analysis. They are as follows:—

| | Level. | Azimuth. | Temperature. |
|---|---|---|---|
| | $''$ | $''$ | $^\circ$ |
| January ... | +0·01 | −0·13 | 0·0 |
| February ... | +0·01 | +0·06 | +0·3 |
| March ... ... | +0·04 | −0·07 | −0·7 |
| April ... ... | −0·13 | +0·08 | +0·5 |
| May ... ... | +0·09 | −0·04 | −0·2 |
| June ... ... | +0·02 | +0·05 | +0·4 |
| July ... ... | −0·04 | −0·03 | −0·3 |
| August ... ... | −0·02 | −0·02 | −0·2 |
| September ... | +0·03 | +0·02 | +0·3 |
| October ... ... | 0·00 | +0·15 | +0·7 |
| November ... | −0·01 | −0·32 | −1·3 |
| December ... | −0·05 | +0·29 | +0·7 |

If these changes are due to temperature, which we may suppose to be only gradually taken up by the masses of stone and metal, and the ground on which the instrument stands, we should expect the lagging effect behind the temperature which is exhibited by the azimuth. The difference of epoch for the first harmonic is about 43°, or about a month and a half; and for the second 48°.

We may get some idea of the kind of phenomena to be expected by studying the law generally assumed for underground temperature, though we must remember that this law is deduced for a homogeneous infinite body bounded by a plane surface, while we are here dealing with a mass of variable density and shape, and that we do not know more than very

roughly which part of it contributes most to the effect under consideration.

A wave of temperature expressible by the term

$$A \sin (nt + a)$$

reaches the depth $x$ under the form

$$Ae^{-kx\sqrt{n}} \sin (nt - kx\sqrt{n} + a),$$

where $k$ is a constant depending on the conductivity of the soil.

If the variation of azimuth were due to the variation of temperature at a definite depth below the surface of some part of the instrument, we should expect the lagging for the second harmonic to be about $\sqrt{2}$ times that for the first harmonic. We see, however, that, although the former is decidedly the greater, it is not quite so large in proportion as this. Again, the ratio of the coefficient of the second harmonic to that of the first is a little greater than the corresponding ratio for temperature, whereas we should expect it to be a little less.

But it is probable that this case of the temperature at a definite depth is not fairly comparable with that before us; we are more likely to get a fair analogy by considering the summation of a series of small changes at continually varying depths, i.e. by integrating the above expression in some way.

Simple integration with respect to the depth from the surface to a considerable distance within the earth would give

$$\int_0^\infty Ae^{-kx\sqrt{n}} \sin (nt - kx\sqrt{n} + a)dx = \frac{A}{k\sqrt{n}} \sin \left(nt - \frac{\pi}{4} + a\right),$$

which would represent, say, the elevation of the surface owing to expansion below. And in this sort of integrated effect we notice an important difference from the former; viz. the lagging is constant for waves of all period, and is nearly 45°. Without laying too much stress on the point, it is interesting to notice that the actual lagging is 43° and 48° for the two harmonics. The truth thus apparently lies between this hypothesis and the former, as we might expect.

On proceeding to consider the level, however, we find that, so far from its lagging behind the temperature, it actually precedes it by nearly as much as the azimuth falls behind. In considering a periodic term it is of course always possible to express it as either preceding another of like period by, say, an eighth-period, or following it by seven-eighths; or if we are at liberty to consider a crest of one to correspond to either a crest or trough of the other, we may express the same anticipation of one-eighth of a period as a lagging of three-eighths. The only reason for considering a decrease of level to correspond to an increase of temperature is that such is found to be the case in the irregular and sudden changes which occur from day to day;

but it is of course quite possible that these rapid changes may be caused by the expansion of quite a different part of the instrument, e.g. much nearer the surface of some part of it. We have then the alternative of considering that the level lags at least $4\frac{1}{2}$ months behind the temperature, perhaps $10\frac{1}{2}$ months; and when we consider that this would mean that the seat of these changes would be at a depth of about 24 feet (or perhaps 56 feet) if the conductivity of the parts of the instrument be even so small as that of rock, this does not seem very likely.*

I was led therefore to speculate as to whether this apparent anticipation of the temperature might not be real; and I venture to hazard the suggestion that a difference of conductivities in the two piers of the transit circle would produce such an effect. If we differentiate the expression

$$Ae^{-kx\sqrt{n}} \sin (nt - kx\sqrt{n} + a)$$

to $k$ we obtain

$$-Ak\sqrt{n}\, e^{-kx\sqrt{n}} \sin \left(nt - kx\sqrt{n} + \frac{\pi}{4} + a\right);$$

that is, this differential effect anticipates the former by an eighth-period, and the relative value of the terms of short period for which $n$ is larger is increased in the proportion of $\sqrt{n}$ to 1. This result is not to be taken numerically, but only as a very rough qualitative illustration of the way in which the temperature possibly influences the level. It will be noticed that the supposition of a difference of conductivities will thus explain the apparent anticipation by the level of the change of temperature, and at the same time the large relative value of the second harmonic in the case of level, which is much more marked than in the case of azimuth.

Now, we have above differentiated the expression for the temperature at a definite point within the mass; but it is probable that some process of integration should first have been employed as in the case of azimuth. We have however previously studied the general effect of integration, and know that it is in the opposite direction to that just mentioned. Generally we should expect these two causes—the gradual filtering of the temperature into the solid mass producing an effect of retardation, and the difference of conductivity between the various parts producing an anticipatory effect, to counterbalance one another to a considerable extent, both in the case of azimuth and level. They have been assigned respectively to the one and the other, first for simplicity, and secondly because the *amount* of the effect to be expected from these respective causes compared with the actual differences of epoch observed in the two cases seems to point to the fact that the variation of azimuth is mainly due to the first, and of level to the second. If it be worth while to

* See *Greenwich Observations* for 1860. Reduction of the observations of the deep-sunk thermometers, by Prof. Everett.

hazard further conjecture as to the reason of this difference of behaviour of the instrument in the two elements we might suppose more definitely that the level error is caused by a warming of the eastern pier more rapidly than the western, whose conductivity is not so great; so that it expands vertically and affects the level, while at the same time the lateral expansion, being symmetrical about the central vertical plane which passes nearly through the pivots, would not affect the azimuth. The piers, or that part of them at least which supports the pivots, not being very thick, the lagging due to gradual conduction will not be very large, and we have the effect of difference of conductivity nearly free from any counteraction.

On the other hand, we must refer the azimuthal variation to changes of temperature probably at some depth below the surface of the soil, which do not happen to affect the level appreciably.

I have examined the variations of level and azimuth at other observatories for a few years to see if there is any similarity between these fluctuations for different instruments. It is somewhat difficult, without expending more time than I can well spare at present, to disentangle their annual variations from changes, secular and irregular, and generally larger than those noticed at Greenwich. I look forward with interest to a discussion by Mr. Finlay of the errors of the Cape Transit Circle promised in the last volume of "Cape Observations" (1879–81). Roughly speaking, there does not seem to be much similarity between the fluctuations of position of different instruments; for instance, the difference of epoch, which has been chiefly considered above, is very variable. And indeed Mr. Ellis pointed out in his paper above referred to how largely the variations of the present Transit Circle differ from those of Troughton's Transit, which occupied nearly the same site. As I have already said, however, in suggesting the above explanations of the changes in position of the Greenwich Transit Circle, we have at our disposal two causes which, combined in varying relative proportion, are capable of explaining fluctuations following or anticipating the temperature by very different periods of time.

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*On the Formulæ for Computing the Apparent Positions of a Satellite, and for Correcting the Assumed Elements of its Orbit.* By A. Marth.

The methods of computation connected with the investigation of a satellite's orbit are comparatively simple and convenient, if they are duly selected to suit directly the coordinates furnished by the observations. If polar-coordinates have been observed, there exists apparently no good reason for not employing polar-coordinates also in the corresponding computations. The present

paper contains the formulæ, which seem to me the most advantageous and handy for computing the apparent positions and the corrections of the assumed elements in the chief cases which come under consideration.

Referring the plane of the satellite's orbit to the plane parallel to the terrestrial equator, let N denote the longitude or Right Ascension of the ascending node; J the inclination; Q the angle between the line of apsides and line of nodes or the departure of the lower apside from the node; $e = \sin\phi$ the eccentricity: $\mu, \epsilon, v$ the mean, eccentric, and true anomaly of the satellite; $u = Q+v$ its true longitude in the orbit reckoned from the node; $u_0 = Q+\mu$ its mean longitude; $r$ the radius vector; $a$ the major semi-axis of the orbit or the satellite's linear mean distance from the planet's centre; $\frac{r}{a} = \rho$, so that $\rho$ is the radius vector expressed in parts of the major semi-axis of the orbit. Further, let A, D denote the apparent Right Ascension and Declination of the planet's centre; $\alpha$, $\delta$ those of the satellite; $\Delta$ the linear distance of the observer from the planet. If the origin of the coordinates is placed in the satellite instead of in the centre of the planet, the strict formulæ become somewhat simplified, but for the purpose $\alpha$ and $\delta$ must be known. In case approximately correct values of $\alpha - A$ and $\delta - D$ are available, like those of the three outer satellites of *Saturn*, published for some years past in the *Monthly Notices*, or if they can be derived directly from the observations, it will be worth while to take advantage of the favourable circumstance.

As most of the observed positions of satellites consist of measures of position-angles $p$ and distances $s$, or are given in polar-coordinates, the formulæ for their proper computation may first be taken into consideration.

If the Earth's position, as seen from the satellite, is referred to the plane of the satellite's orbit by the longitude U + 180° and latitude B, and if P is the position-angle of the pole of the orbit (in Right Ascension N − 90° and Declination 90° − J) at the geocentric place of the satellite, the values of U, B, P are found from those of N, J, $\alpha$, $\delta$ by means of the equations:

$$\begin{aligned}
\cos B \sin U &= \cos\delta \sin(\alpha - N) \cos J + \sin\delta \sin J \\
\cos B \cos U &= \cos\delta \cos(\alpha - N) \\
\sin B &= \cos\delta \sin(\alpha - N) \sin J - \sin\delta \cos J \\
\cos B \sin P &= \quad -\cos(\alpha - N) \sin J \\
\cos B \cos P &= \sin\delta \sin(\alpha - N) \sin J + \cos\delta \cos J
\end{aligned}$$

or by equivalent formulæ.

The satellite's orbital longitude $u = Q + v$, and also $\rho$ being deduced from the mean anomaly $\mu$, either by the usual formulæ:

$$\begin{aligned}
\epsilon - e\omega^\circ \sin\epsilon &= \mu \qquad\qquad \omega^\circ = 57^\circ\!\cdot\!296 = \frac{1}{\text{arc } 1^\circ} \\
\rho \sin v &= \sin\epsilon \cos\phi \\
\rho \cos v &= \cos\epsilon - e
\end{aligned}$$

or by the series for the equation of the centre $v-\mu$ and $\log \rho$, the values of the position-angle $p$ and of the distance $s$ corresponding to $u$ are found by means of the equations

$$\sin\sigma \sin(p-P)=\sin(u-U)$$
$$\sin\sigma \cos(p-P)=\cos(u-U)\sin B$$
$$\sin s=\frac{a}{\Delta}\,.\,\rho \sin\sigma$$

in which $\sigma$ is the arc on the sphere between the geocentric and planetocentric place of the satellite, or, without the introduction of $\sigma$, by

$$\sin s \sin(p-P)=\frac{a}{\Delta}\rho \sin(u-U)$$

$$\sin s\cos(p-P)=\frac{a}{\Delta}\rho\cos(u-U)\sin B$$

The position-angle $p$ thus computed refers to the Declination-circle passing through the satellite. In case the observed position-angle refers to the Declination-circle passing through the point midway between the planet's centre and the satellite, a correction $=-\frac{1}{2}s\sin p\tan\delta$ must, when a strict comparison is required, be added to the computed $p$.

If A, D are substituted for $a$, $\delta$ in the formulæ for U, B, P, so that their ensuing values refer to the centre of the planet instead of the satellite, the correction of the computed $p$ will be $=+\frac{1}{2}s\sin p\tan D$, the computed $\sigma$ (which must be taken between 90° and 180°, when $\cos(u-U)$ is negative) represents the arc between the geocentric place of the planet and the planetocentric place of the satellite, and the value of $s$ must be found indirectly from the equation

$$\sin s=\frac{a}{\Delta}\rho\sin(\sigma-s),$$

if the employment of the equations

$$\Delta_1\sin s\sin(p-P)=a\rho\sin(u-U)$$
$$\Delta_1\sin s\cos(p-P)=a\rho\cos(u-U)\sin B$$
$$\Delta_1\cos s\qquad=a\rho\cos(u-U)\cos B+\Delta,$$

in which $\Delta_1$ denotes the distance of the satellite from the earth, is to be avoided.

The equations of condition for correcting the assumed elements of the orbit gain in clearness and simplicity by the introduction of

$$\sin\sigma\sin\tau=\sin B$$
$$\sin\sigma\cos\tau=\cos B\sin(u-U)$$
$$\cos\sigma=\cos B\cos(u-U)$$

which serve, at the same time, as a partial control upon the equations for finding $p$:

$$\sin\sigma\sin(p-P)=\sin(u-U)$$
$$\sin\sigma\cos(p-P)=\cos(u-U)\sin B$$
$$\sin s=\frac{a}{\Delta}.\rho\sin\sigma$$

The differentiation of these equations gives:

$$\sin\sigma dp=\sin\tau.d(u-U)-\cos\tau\cos(u-U)dB+\sin\sigma dP$$
$$d\sigma=\cos\tau.d(u-U)+\sin\tau\cos(u-U)dB$$

But

$$\cos B dU=-\cos U\sin B dJ-\cos P\cos\delta dN$$
$$\cos B dP=-\cos U dJ \qquad +\sin U\sin J dN$$
$$dB=+\sin U dJ \qquad -\cos U\sin J dN.$$

Hence, after some reductions:

$$\sin\sigma dp=\sin\tau du-\cos\tau\sin u dJ+(\cos\sigma\cos p\cos\delta-\sin\sigma\sin\delta)dN$$
$$d\sigma=\cos\tau du+\sin\tau\sin u dJ+\sin p\cos\delta dN$$
$$\rho\sin\sigma.\omega^\circ.\frac{ds}{s}=\rho\cos\sigma d\sigma+\sin\sigma\omega^\circ d\rho+\rho\sin\sigma\omega^\circ.\frac{da}{a}.$$

The differential expressions of $u$, the satellite's true longitude, with respect to its mean longitude $u_0$ and Q and $\phi$, are:

$$\rho du=\frac{\cos\phi}{\rho}du_0+\left(\rho-\frac{\cos\phi}{\rho}\right)dQ+(1+\rho\sec^2\phi)\sin v.\cos\phi d\phi$$
$$=(1+e\cos v)\sec\phi du_0-\{2\cos v\}\tan\phi dQ+\{2\sin v\}\cos\phi d\phi$$

in which the coefficients in { } brackets denote the following equivalents, among which the most convenient, according to facilities at hand, may be selected:

$$\{2\cos v\}=\cos v+\cos\epsilon\cos\phi+\tan\tfrac{1}{2}\phi$$
$$=\frac{(2+e\cos v)\cos v+e+\tan\frac{1}{2}\phi\cos^2\phi}{1+e\cos v}$$
$$=\left(2-\frac{e\cos v}{1+e\cos v}\right)\cos v+\frac{e\cos\phi+\tan\frac{1}{2}\phi}{1+e\cos v}$$
$$=(1+\rho\sec^2\phi)\cos v+\rho(\tan\phi+\tan\tfrac{1}{2}\phi\sec^2\phi)$$
$$\{2\sin v\}=\sin v+\sin\epsilon\sec\phi$$
$$=\frac{2+e\cos v}{1+e\cos v}\sin v$$
$$=\left(2-\frac{e\cos v}{1+e\cos v}\right)\sin v$$
$$=(1+\rho\sec^2\phi)\sin v.$$

The substitution of these expressions and of

$$\omega^\circ d\rho=\tan\phi\sin v du_0-\sin v.\tan\phi dQ-\cos v.\cos\phi d\phi$$

in the equations for $\sin\sigma dp$ and $ds$ leads to the equations be-

tween the variations of the computed coordinates and the variations of the assumed elements

$$\rho \sin \sigma \delta p = \sin \tau \,.\, \frac{\cos \phi}{\rho} \,.\, \delta u_0$$
$$- \sin \tau \,.\, \{2 \cos v\}\, \omega^\circ (\tan \phi + \delta e) \sin \delta Q$$
$$+ \sin \tau \,.\, \{2 \sin v\}\, \omega^\circ [(\tan \phi + \delta e) \cos \delta Q - \tan \phi]$$
$$- \rho \cos \tau \sin u \delta J$$
$$+ \rho (\cos \sigma \cos p \cos \delta - \sin \sigma \sin \delta)\, \delta N$$

$$\rho \sin \sigma \,.\, \omega^\circ \frac{\delta s}{s} = (\cos \sigma \cos \tau \,.\, \frac{\cos \phi}{\rho} + \tan \phi \sin \sigma \sin v)\delta u_0$$
$$- (\cos \sigma \cos \tau \{2 \cos v\} + \sin \sigma \sin v)\, \omega^\circ (\tan \phi + \delta e) \sin \delta Q$$
$$+ (\cos \sigma \cos \tau \{2 \sin v\} - \sin \sigma \cos v)\, \omega^\circ [(\tan \phi + \delta e) \cos \delta Q - \tan \phi]$$
$$+ \rho \cos \sigma \sin \tau \sin u \,.\, \delta J$$
$$+ \rho \cos \sigma \sin p \cos \delta \,.\, \delta N$$
$$+ \rho \sin \sigma \,.\, \omega^\circ \frac{\delta a}{a} \,.$$

In order to guard against some possible oversight or error in the interpretation of the variations connected with the eccentricity if they are written in the form $\tan \phi \, \delta Q$ and $\cos \phi \, \delta \phi$, I have substituted in these equations for

$$\tan \phi \delta Q \; \ldots\ldots \; \omega^\circ (\tan \phi + \delta e) \sin \delta Q$$

and for

$$\cos \phi \delta \phi \; \ldots . \; \omega^\circ [(\tan \phi + \delta e) \cos \delta Q - \tan \phi]$$

expressions which represent the true meaning of these variations, and will lead to right deductions of the corrections of Q and $e$ in all cases. If not thus interpreted the expressions $\tan \phi \, \delta Q$ and $\cos \phi \, \delta \phi$ or $\delta e$ may obviously be misleading, and may give very incorrect results whenever the assumed values of Q and $e$ require more than small corrections.

If, instead of $\delta Q$ and $\delta e$, the variations of suitable functions of Q and $e$ are to be introduced, the equations for $\rho \, du$ and $d\rho$ suggest the advantage of selecting for the purpose not $e \sin Q$ and $e \cos Q$, but E sin Q and E cos Q, where E is such a function of $e$ or $\phi$ that

$$\tan \phi dE = E de = E \cos \phi d\phi .$$

Putting accordingly

$$E = e \,.\, \sec^2 \tfrac{1}{2}\phi \,.\, c^{-2 \sin^2 \frac{1}{2}\phi} = 2 \tan \tfrac{1}{2}\phi \,.\, c^{-2 \sin^2 \frac{1}{2}\phi} \qquad (c \text{ basis of nat. log.})$$

the differential coefficients of $u$ and $\rho$ with respect to E sin Q and E cos Q will be

$$\rho du = \,..\, - \frac{(2 + e \cos v) \cos u + (e \cos \phi + \tan \frac{1}{2}\phi) \cos Q}{1 + e \cos v} \,.\, \omega^\circ \,.\, \frac{\tan \phi}{E} \,.\, d(E \sin Q)$$
$$+ \frac{(2 + e \cos v) \sin u + (e \cos \phi + \tan \frac{1}{2}\phi) \sin Q}{1 + e \cos v} \,.\, \omega^\circ \,.\, \frac{\tan \phi}{E} \,.\, d(E \cos Q),$$

$$d\rho = \ldots . - \sin u \,.\, \frac{\tan \phi}{E} \,.\, d(E \sin Q) - \cos u \,.\, \frac{\tan \phi}{E} \,.\, d(E \cos Q).$$

Hence the eccentricity terms in the equations of condition for $\dot{\delta p}$ and $\delta s$ become

$$\rho \sin \sigma \dot{\delta p} = \ldots - \sin \tau \,.\, \frac{(2+e\cos v)\cos u + (e\cos\phi + \tan\frac{1}{2}\phi)\cos Q}{1+e\cos v} \,.\, \omega^{\circ} \,.\, \frac{\tan\phi}{E} \,.\, \delta(E\sin Q)$$

$$+ \sin\tau \,.\, \frac{(2+e\cos v)\sin u + (e\cos\phi+\tan\frac{1}{2}\phi)\sin Q}{1+e\cos v} \,.\, \omega^{\circ} \,.\, \frac{\tan\phi}{E} \,.\, \delta(E\cos Q)$$

$$\rho\sin\sigma\frac{\delta s}{s} = \ldots - \left(\cos\sigma\cos\tau \,.\, \frac{(2+e\cos v)\cos u + (e\cos\phi+\tan\frac{1}{2}\phi)\cos Q}{1+e\cos v} + \sin\sigma\sin u\right) \,.\, \frac{\tan\phi}{E} \,.\, \delta(E\sin Q)$$

$$+ \left(\cos\sigma\cos\tau \,.\, \frac{(2+e\cos v)\sin u + (e\cos\phi+\tan\frac{1}{2}\phi)\sin Q}{1+e\cos v} - \sin\sigma\cos u\right) \,.\, \frac{\tan\phi}{E} \,.\, \delta(E\cos Q).$$

Though in this way the corrections of the assumed values of Q and $e$ might be properly found and mistaken deductions avoided, the way would be needlessly circuitous; for, by substituting in the foregoing expressions for $\delta(E\sin Q)$ and $\delta(E\cos Q)$ their values

$$(E+\delta E)\sin(Q+\delta Q) - E\sin Q, \text{ and}$$
$$(E+\delta E)\cos(Q+\delta Q) - E\cos Q,$$

and by eliminating Q, the expressions are obtained which are already given in the equations of condition, and which, while of equal strictness, are obviously preferable on account of their greater simplicity and directness. Moreover, they allow the motion of the apses, if approximately known, to be easily taken into account.

The equations of condition have yet to be so adjusted that the differences between the observed and the computed co-ordinates are measured by the same unit. It will depend on the character of the measured position-angles and distances whether it is preferable to express the differences in seconds of arc or in units corresponding to an arc of one degree on a circle of suitable radius, and also how far the ensuing rules are better modified or altered.

If $\sin a_0 = \frac{a}{\Delta_0}$, where $\Delta_0$ is some conveniently fixed value of $\Delta$ (not differing greatly from the average of the distances $\Delta$ at which observations are taken), and if $\frac{\Delta_0}{\Delta} = \nu$, the angular distances $s$ of the satellite will be

$$s = a_0\nu \,.\, \rho\sin\sigma.$$

Making

$$\frac{a_0}{57\cdot3}=\kappa$$

the adopted unit, the equations of conditions will be

$$\begin{aligned}
\frac{s}{a_0}\,\delta p = &+\nu\sin\tau\,.\,\frac{\cos\phi}{\rho}\,.\,\delta u_0\\
&-\nu\sin\tau\,.\,\{2\cos v\}\,.\,\omega^\circ(\tan\phi+\delta e)\sin\delta Q\\
&+\nu\sin\tau\,.\,\{2\sin v\}\,.\,\omega^\circ[(\tan\phi+\delta e)\cos\delta Q-\tan\phi\\
&-\nu\rho\cos\tau\,.\,\sin u\,.\,\delta J\\
&+\nu\rho(\cos\sigma\cos p\cos\delta-\sin\sigma\sin\delta)\,.\,\delta N\\
\frac{\delta s}{\kappa} = &+\nu(\cos\sigma\cos\tau\,.\,\frac{\cos\phi}{\rho}+\tan\phi\sin\sigma\sin v)\,.\,\delta u_0\\
&-\nu(\cos\sigma\cos\tau\,.\,\{2\cos v\}+\sin\sigma\sin v)\,.\,\omega^\circ(\tan\phi+\delta e)\sin\delta Q\\
&+\nu(\cos\sigma\cos\tau\,.\,\{2\sin v\}-\sin\sigma\cos v)\,.\,\omega^\circ[(\tan\phi+\delta e)\cos\delta Q-\tan\phi]\\
&+\nu\rho\cos\sigma\sin\tau\,.\,\sin u\,.\,\delta J\\
&+\nu\rho\cos\sigma\sin p\cos\delta\,.\,\delta N\\
&+\frac{s}{a_0}\,.\,\frac{\delta a_0}{\kappa}.
\end{aligned}$$

If the differences between the observed and computed coordinates are expressed in seconds of arc, the equations become

$$\begin{aligned}
\frac{s}{57\cdot3}\,\delta p = &+\nu\sin\tau\,.\,\frac{\cos\phi}{\rho}\,.\,\kappa\delta u_0\\
&-\nu\sin\tau\,.\,\{2\cos v\}\,.\,a_0(\tan\phi+\delta e)\sin\delta Q\\
&+\nu\sin\tau\,.\,\{2\sin v\}\,.\,a_0[(\tan\phi+\delta e)\cos\delta Q-\tan\phi]\\
&-\nu\rho\cos\tau\,.\,\sin u\,.\,\kappa\delta J\\
&+\nu\rho(\cos\sigma\cos p\cos\delta-\sin\sigma\sin\delta)\,.\,\kappa\delta N\\
\delta s = &+\nu(\cos\sigma\cos\tau\,.\,\frac{\cos\phi}{\rho}+\tan\phi\sin\sigma\sin v)\,.\,\kappa\delta u_0\\
&-\nu(\cos\sigma\cos\tau\,.\,\{2\cos v\}+\sin\sigma\sin v)\,.\,a_0(\tan\phi+\delta e)\sin\delta Q\\
&+\nu(\cos\sigma\cos\tau\,.\,\{2\sin v\}-\sin\sigma\cos v)\,.\,a_0[(\tan\phi+\delta e)\cos\delta Q-\tan\phi]\\
&+\nu\rho\cos\sigma\sin\tau\,.\,\sin u\,.\,\kappa\delta J\\
&+\nu\rho\cos\sigma\sin p\cos\delta\,.\,\kappa\delta N\\
&+\frac{s}{a_0}\,.\,\delta a_0.
\end{aligned}$$

The formulæ are here written out in full. Abbreviated notations for the quantities which are to be determined and for their coefficients will, of course, be substituted in actual computations.

The preceding equations are valid for orbits of any assumed

ellipticity. For assumed circular elements they get considerably simplified, and become

$$
\begin{aligned}
\frac{s}{a_0}\delta p = &+\nu \sin\tau \,.\, \delta u \\
&-\nu \sin\tau \,.\, \cos u \,.\, 2\phi \sin Q \\
&+\nu \sin\tau \,.\, \sin u \,.\, 2\phi \cos Q \\
&-\nu \cos\tau \,.\, \sin u \,.\, \delta J \\
&+\nu (\cos\sigma \cos p \cos\delta - \sin\sigma \sin\delta) \,.\, \delta N \\
\frac{\delta s}{\kappa} = &+\nu \cos\sigma \cos\tau \,.\, \delta u \\
&-\nu (\cos\sigma \cos\tau \,.\, \cos u + \tfrac{1}{2} \sin\sigma \sin u) \,.\, 2\phi \sin Q \\
&+\nu (\cos\sigma \cos\tau \,.\, \sin u - \tfrac{1}{2} \sin\sigma \cos u) \,.\, 2\phi \cos Q \\
&+\nu \cos\sigma \sin\tau \,.\, \sin u \,.\, \delta J \\
&+\nu \cos\sigma \sin p \cos\delta \,.\, \delta N \\
&+\frac{s}{a_0} \,.\, \frac{\delta a_0}{\kappa}.
\end{aligned}
$$

They must be multiplied by $\kappa$ if the differences are to be expressed in seconds.

The orbital longitudes $u$, U, Q employed in the preceding formulæ are reckoned from the node N, and this reckoning is most suitable whenever the inclination J is considerable. But if J is only of moderate amount, as in the case of the orbits of *Saturn's* satellites, the determination of the nodal point is considerably uncertain, and this uncertainty rapidly increases with the decrease of J. By adding the longitude of N to the longitudes reckoned from N the uncertainty is evaded, and the longitudes in the orbit start from a properly fixed point.

Putting $u+N=l$ and $U+N=L$, the formulæ for finding $p$ and the sin and cos of $\sigma$ and $\tau$ require merely the substitution of $l-L$ for $u-U$:

$$
\begin{aligned}
&\sin\sigma \sin(p-P) = \sin(l-L) && \sin\sigma \sin\tau = \sin B \\
&\sin\sigma \cos(p-P) = \cos(l-L) \sin B && \sin\sigma \cos\tau = \cos B \sin(l-L) \\
&\sin s = \frac{a}{\Delta} \,.\, \rho \sin\sigma \text{ or } s = a_0\nu \,.\, \rho \sin\sigma && \cos\sigma = \cos B \cos(l-L).
\end{aligned}
$$

The differential expressions for $\sin \sigma dp$ and $d\sigma$ become by the substitution of $dl-dN$ for $du$

$$
\begin{aligned}
\sin\sigma\, dp &= \sin\tau \,.\, dl - \cos\tau \sin u \,.\, dJ + (\cos\sigma \cos p \cos\delta - \sin\sigma \sin\delta - \sin\tau) dN \\
d\sigma &= \cos\tau \,.\, dl + \sin\tau \sin u \,.\, dJ + (\sin p \cos\delta - \cos\tau) dN.
\end{aligned}
$$

But

$$
\begin{aligned}
\cos\sigma \cos p \cos\delta - \sin\sigma \sin\delta &= \sin\tau \cos J + \cos\tau \cos u \sin J \\
\sin p \cos\delta &= \cos\tau \cos J - \sin\tau \cos u \cos J.
\end{aligned}
$$

Hence

$$
\begin{aligned}
\sin\sigma dp &= \sin\tau \,.\, dl + [\cos\tau \cos(l-N) - \tan\tfrac{1}{2}J \sin\tau] \sin J \,.\, dN - \cos\tau \sin(l-N) dJ \\
d\sigma &= \cos\tau \,.\, dl - [\sin\tau \cos(l-N) + \tan\tfrac{1}{2}J \cos\tau] \sin J \,.\, dN + \sin\tau \sin(l-N) dJ
\end{aligned}
$$

The equations of condition between the variations of the coordinates and the variations of functions of the elements become accordingly

$$\frac{s}{57\cdot3}\delta p = +\nu\sin\tau.\frac{\cos\phi}{\rho}.\kappa\delta l_0$$
$$-\nu\sin\tau.\{2\cos v\}.a_0(\tan\phi+\delta e)\sin\delta(Q+N)$$
$$+\nu\sin\tau.\{2\sin v\}.a_0[(\tan\phi+\delta e)\cos\delta(Q+N)-\tan\phi]$$
$$+\nu\rho[\cos\tau\cos(l-N)-\tan\tfrac{1}{2}J\sin\tau].a_0\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\sin\delta N$$
$$-\nu\rho\cos\tau\sin(l-N).a_0\left[\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\cos\delta N-\sin J\right]$$

$$\delta s = +\nu\left(\cos\sigma\cos\tau.\frac{\cos\phi}{\rho}+\tan\phi\sin\sigma\sin v\right).\kappa\delta l_0$$
$$-\nu(\cos\sigma\cos\tau.\{2\cos v\}+\sin\sigma\sin v).a_0(\tan\phi+\delta e)\sin\delta(Q+N)$$
$$+\nu(\cos\sigma\cos\tau.\{2\sin v\}-\sin\sigma\cos v).a_0[(\tan\phi+\delta e)\cos\delta(Q+N)-\tan\phi]$$
$$-\nu\rho\cos\sigma[\sin\tau\cos(l-N)+\tan\tfrac{1}{2}J\cos\tau].a_0\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\sin\delta N$$
$$+\nu\rho\cos\sigma.\sin\tau\sin(l-N).a_0\left[\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\cos\delta N-\sin J\right]$$
$$+\frac{s}{a_0}.\delta a_0$$

In order to guard against incorrect deductions of the corrections of the node and inclination, which might occur, if the terms sin J . δN and δJ were kept without proper interpretation, I have substituted for

$$\kappa.\sin J.\delta N \;\ldots\; a_0\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\sin\delta N$$

and for

$$\kappa.\delta J \;\ldots\; a_0\left[\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\cos\delta N-\sin J\right]$$

expressions which, as in the analogous case of the eccentricity terms, represent the true meaning of these terms, and cannot mislead. By this simple substitution all the advantages for the correctness of the deductions are secured, which otherwise might be gained by the introduction of the variations of tan $\frac{1}{2}$J sin N and tan $\frac{1}{2}$J cos N, but without their attending drawbacks, as mathematical readers may easily satisfy themselves.

The quantities

$$\kappa\delta l_0,\; a_0(\tan\phi+\delta e)\sin\delta(Q+N),\; a_0[(\tan\phi+\delta e)\cos\delta(Q+N)-\tan\phi],$$
$$a_0\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\sin\delta N,\; a_0\left[\left(\sin J+\frac{\delta J}{\omega^\circ}\right)\cos\delta N-\sin J\right]$$

which are to be treated as the unknown quantities, will in the formulæ for actual computation, of course, be represented by single letters.

For assumed circular elements the equations of condition become

$$\begin{aligned}
\frac{s}{57^{\cdot}3}\delta p = &+\nu\sin\tau\,.\,\kappa\delta l\\
&-\nu\sin\tau\,.\,\cos l\,.\,2\kappa\phi\sin(Q+N)\\
&+\nu\sin\tau\,.\,\sin l\,.\,2\kappa\phi\cos(Q+N)\\
&+\nu\left[\cos\tau\cos(l-N)-\tan\tfrac{1}{2}J\sin\tau\right].\,a_0\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\sin\delta N\\
&-\nu\cos\tau\sin(l-N)\,.\,a_0\left[\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\cos\delta N-\sin J\right]
\end{aligned}$$

$$\begin{aligned}
\delta s = &+\nu\cos\sigma\cos\tau\,.\,\kappa\delta l_0\\
&-\nu(\cos\sigma\cos\tau\,.\,\cos l+\tfrac{1}{2}\sin\sigma\sin l)\,.\,2\kappa\phi\sin(Q+N)\\
&+\nu(\cos\sigma\cos\tau\,.\,\sin l-\tfrac{1}{2}\sin\sigma\cos l)\,.\,2\kappa\phi\cos(Q+N)\\
&-\nu\cos\sigma\left[\sin\tau\cos(l-N)+\tan\tfrac{1}{2}J\cos\tau\right].\,a_0\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\sin\delta N\\
&+\nu\cos\sigma\,.\,\sin\tau\sin(l-N)\,.\,a_0\left[\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\cos\delta N-\sin J\right]\\
&+\frac{s}{a_0}\,.\,\delta a_0.
\end{aligned}$$

In turning from the consideration of the proper treatment of measured polar coordinates to that of rectangular coordinates, it is obviously expedient to take first the special case of *Saturn's* satellites, when their rectangular coordinates parallel to the axes of the ring are either measured or estimated. In measuring the distances from the axes it is essential that the position-angles in which the measures are taken should be distinctly stated, so that if they differ from the computed position-angles of the axes which represent the fundamental plane, to which the orbits of the satellites are to be referred, the necessary corrections may be applied.

If L, B, P have the same significance as before in rëference to the assumed plane of the ring, the coordinates $x''$, $y''$ parallel to the axes of the ring are

$$s\sin(p-P)=x''=a_0\nu\,.\,\rho\sin(l-L)$$

$$s\cos(p-P)=y''=a_0\nu\,.\,\rho\cos(l-L)\sin B$$

$$\begin{aligned}
\delta x'' = &+\nu\left[\cos(l-L)+e\cos M\right].\,\kappa\sec\phi\delta l_0\\
&-\nu\left[\cos(l-L)(\cos\epsilon\cos\phi+\tan\tfrac{1}{2}\phi)+\cos M\right].\,a_0(\tan\phi+\delta e)\sin\delta(Q+N)\\
&+\nu\left[\cos(l-L)\sin\epsilon\sec\phi+\sin M\right].\,a_0\left[(\tan\phi+\delta e)\cos\delta(Q+N)-\tan\phi\right]\\
&-\nu\rho\,.\,\tan\tfrac{1}{2}J\cos(l-L)\,.\,a_0\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\sin\delta N\\
&+\frac{x''}{a_0}\,.\,\delta a_0.
\end{aligned}$$

$$\begin{aligned}
\delta y'' = &-\nu\sin B\left[\sin(l-L)-e\sin M\right].\,\kappa\sec\phi\delta l_0\\
&+\nu\sin B\left[\sin(l-L)(\cos\epsilon\cos\phi+\tan\tfrac{1}{2}\phi)-\sin M\right].a_0(\tan\phi+\delta e)\sin\delta(Q+N)\\
&-\nu\sin B\left[\sin(l-L)\sin\epsilon\sec\phi+\cos M\right].\,a_0\left[(\tan\phi+\delta e)\cos\delta(Q+N)-\tan\phi\right]\\
&+\nu\rho\left[\cos B\cos(l-N)-\tan\tfrac{1}{2}J\sin B\sin(l-L)\right].\,a_0\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\sin\delta N\\
&+\nu\rho\cos B\sin(l-N)\,.\,a_0\left[\left(\sin J+\frac{\delta J}{\omega^{\circ}}\right)\cos\delta N-\sin J\right]\\
&+\frac{y''}{a_0}\,.\,\delta a_0.
\end{aligned}$$

For convenience M is put instead of L−(Q+N). If the eccentric anomaly $\epsilon$ is not available

$$\frac{\cos v + e\cos\phi + \tan\frac{1}{2}\phi}{1 + e\cos v} \text{ must be put for } \cos\epsilon\cos\phi + \tan\tfrac{1}{2}\phi$$

and

$$\frac{\sin v}{1 + e\cos v} \text{ for } \sin\epsilon\sec\phi.$$

For assumed circular elements the equations of condition become

$$\begin{aligned}
\delta x'' = &+\nu\cos(l-\mathrm{L})\,.\,\kappa\delta l \\
&-\nu[\cos(l-\mathrm{L})\cos l + \cos\mathrm{L}]\,.\,a_0 e\sin(\mathrm{Q}+\mathrm{N}) \\
&+\nu[\cos(l-\mathrm{L})\sin l + \sin\mathrm{L}]\,.\,a_0 e\cos(\mathrm{Q}+\mathrm{N}) \\
&-\nu\tan\tfrac{1}{2}\mathrm{J}\cos(l-\mathrm{L})\,.\,a_0\left(\sin\mathrm{J} + \frac{\delta\mathrm{J}}{\omega^\circ}\right)\sin\delta\mathrm{N} \\
&+\frac{x''}{a_0}\,.\,\delta a_0.
\end{aligned}$$

$$\begin{aligned}
\delta y'' = &-\nu\sin\mathrm{B}\,.\,\sin(l-\mathrm{L})\,.\,\kappa\delta l \\
&+\nu\sin\mathrm{B}[\sin(l-\mathrm{L})\cos l - \sin\mathrm{L}]\,.\,a_0 e\sin(\mathrm{Q}+\mathrm{N}) \\
&-\nu\sin\mathrm{B}[\sin(l-\mathrm{L})\sin l + \cos\mathrm{L}]\,.\,a_0 e\cos(\mathrm{Q}+\mathrm{N}) \\
&-\nu[\cos\mathrm{B}\cos(l-\mathrm{N}) - \tan\tfrac{1}{2}\mathrm{J}\sin\mathrm{B}\sin(l-\mathrm{L})]\,.\,a_0\left(\sin\mathrm{J} + \frac{\delta\mathrm{J}}{\omega^\circ}\right)\sin\delta\mathrm{N} \\
&+\nu\cos\mathrm{B}\sin(l-\mathrm{N})\,.\,a_0\left[\left(\sin\mathrm{J} + \frac{\delta\mathrm{J}}{\omega^\circ}\right)\cos\delta\mathrm{N} - \sin\mathrm{J}\right] \\
&+\frac{y''}{a_0}\,.\,\delta a_0.
\end{aligned}$$

In case the $x$ ordinates are not measured micrometrically, but estimated by comparison with certain definite points of the major axis of the ring, the proper unit for $x$ and for the semi-axis of the satellite's orbit will obviously be the semi-diameter of *Saturn's* equator. If $(a)$ is the length of the semi-axis expressed in such units, the computed

$$x = (a)\rho\sin(l-\mathrm{L})$$

and the equations of condition require merely the substitution of $(a)$ for $a_0\,\nu$.

Though the range of such estimations of $x$ is limited, there is the great advantage that they can be made without micrometer, and even with a rather unsteady instrument, and that when taken with due care and circumspection at the right times, they yield in accuracy only to the best micrometrical measurements. Observations which fix the times of the conjunctions of the satellites with the limbs of the ball and the ends of the ring in the four quadrants are of great value, not only in investigations

of the orbital longitudes of the satellites, but also in examining the dimensions of the ball and ring.

If the observed positions of the satellite in reference to the planet's centre consist of differences of Right Ascension and Declination, or are given in equivalent rectangular coordinates, the frequently used method for their computation may be followed, which Bessel employs in his investigation of the orbit of *Titan* ("Astr.-Nachr.," Nos. 193–195). His auxiliary angles $f$, F, $g$, G, $h$, H, referred to the geocentric place of the planet A, D, may be found by means of the formulæ *

$$\begin{aligned} \sin f \sin F &= -\sin(A-N) \\ \sin f \cos F &= +\cos(A-N)\cos J \\ \cos f &= -\cos(A-N)\sin J \\ \sin f \sin E &= -\sin(A-N)\sin J \\ \sin f \cos E &= +\cos J \end{aligned} \qquad \begin{aligned} \sin g \sin(G-F) &= -\sin(D+E) \\ \sin g \cos(G-F) &= +\cos(D+E)\cos f \\ \cos g &= +\cos(D+E)\sin f \\ \sin h \sin(H-F) &= +\cos(D+E) \\ \sin h \cos(H-F) &= -\sin(D+E)\cos f \\ \cos h &= +\sin(D+E)\sin f. \end{aligned}$$

---

* The values of $b$, B, $c$, C in the expressions for a planet's or comet's heliocentric coordinates referred to the equator—

$$x = r \sin a \sin(A' + v),$$
$$y = r \sin b \sin(B' + v),$$
$$z = r \sin c \sin(C' + v),$$

may be found, in a similar manner, by means of the formulæ

$$\begin{aligned} \sin a \sin E &= +\sin i \cos \Omega \\ \sin a \cos E &= +\cos i \\ \cos a &= +\sin i \sin \Omega \\ \sin a \sin A &= +\cos \Omega \\ \sin a \cos A &= -\sin \Omega \cos i \\ A' &= A + \omega \end{aligned} \qquad \begin{aligned} \sin b \sin(B-A) &= -\cos(E+\epsilon) \\ \sin b \cos(B-A) &= +\sin(E+\epsilon)\cos a \\ \cos b &= -\sin(E+\epsilon)\sin a \\ \sin c \sin(C-A) &= -\sin(E+\epsilon) \\ \sin c \cos(C-A) &= -\cos(E+\epsilon)\cos a \\ \cos c &= +\cos(E+\epsilon)\sin a \end{aligned}$$

so that the $B' + v$ and $C' + v$ in the expressions for $y$ and $z$ are obtained by simply adding B − A and C − A to the values of $A' + v$.

Are these convenient formulæ for $b$, B, $c$, C not to be found anywhere in print? Considering that they refer to computations of such frequent occurrence, it is not easy to assume that they have not been pointed out before.

In case the inclination $i$ is of moderate amount, it may be worth while, for greater accuracy, to determine A by computing

$$\sin \nu = \tan \tfrac{1}{2} i \,.\, \sin \Omega \,.\, \sin E$$

which makes $$A = \Omega + 90^\circ - \nu.$$

If formulæ for control are required,

$$\sin b \sin B = \sin \Omega \cos \epsilon$$
$$\sin c \sin C = \sin \Omega \sin \epsilon$$
$$\tan(C - B) = \frac{\cos a}{\cos b \cos c}$$

may serve the purpose.

The positions of the satellite are then found by

$$\begin{aligned}\Delta_{,}\sin s\sin p &= r\sin f\sin(\mathrm{F}+u) &&= \Delta\,.\,\xi\\ \Delta_{,}\sin s\cos p &= r\sin g\sin(\mathrm{G}+u) &&= \Delta\,.\,y\\ \Delta_{,}\cos s &= \Delta + r\sin h\sin(\mathrm{H}+a) &&= \Delta\,.\,(1+\zeta);\end{aligned}$$

or, if the difference between $s$ and $\omega''\tan s$ is neglected, the rectangular coordinates by

$$x'' = \frac{\omega''}{\Delta}\,.\,\frac{r}{1+\zeta}\sin f\sin(\mathrm{F}+u)\qquad \omega'' = \frac{1}{\operatorname{arc} 1''}$$
$$y'' = \frac{\omega''}{\Delta}\,.\,\frac{r}{1+\zeta}\sin g\sin(\mathrm{G}+u).$$

By the substitution of $a$, $\delta$ for A, D in the computations of the auxiliary angles $f$, F, $g$, G, or by computing their values, not for the apparent place of the planet, but for that of the satellite, the divisor $1+\zeta$ will be got rid of, and the formulæ become simplified. If that course is adopted they will be

$$x'' = \omega''\sin s\sin p = \omega''\cos\mathrm{D}\sin(a-\mathrm{A}) = a_0\nu\rho\,.\,\sin f\sin(\mathrm{F}+u)$$
$$y'' = \omega''\sin s\cos p = \omega''\sin(\delta-\mathrm{D}) - x''\,.\,\tan\tfrac{1}{2}(a-\mathrm{A})\sin\delta = a_0\nu\rho\,.\,\sin g\sin(\mathrm{G}+u)$$

or, if $\mathrm{F}' = \mathrm{F}+\mathrm{Q}$, $\mathrm{G}' = \mathrm{G}+\mathrm{Q}$,

$$x'' = a_0\nu\sin f\,.\,\rho\sin(\mathrm{F}'+v)$$
$$y'' = a_0\nu\sin g\,.\,\rho\sin(\mathrm{G}'+v).$$

The equations of condition are

$$\begin{aligned}\delta x'' = &+\nu\sin f[\cos(\mathrm{F}'+v)+e\cos\mathrm{F}']\,.\,\kappa\sec\phi\,\delta l_0\\ &-\nu\sin f[\cos(\mathrm{F}'+v)(\rho\cos v\cos\phi+e\cos\phi+\tan\tfrac{1}{2}\phi)+\cos\mathrm{F}']\,.\\ &\qquad a_0(\tan\phi+\delta e)\sin\delta(\mathrm{Q}+\mathrm{N})\\ &+\nu\sin f[\cos(\mathrm{F}'+v)\,.\,\rho\sin v\sec^2\phi-\sin\mathrm{F}']\,.\,a_0[(\tan\phi+\delta e)\cos\delta(\mathrm{Q}+\mathrm{N})\\ &\qquad -\tan\phi]\\ &+\nu\rho\,.\,\tan\tfrac{1}{2}\mathrm{J}\,.\,\cos(l-\mathrm{N}+a-\mathrm{N})\,.\,a_0\left(\sin\mathrm{J}+\frac{\delta\mathrm{J}}{\omega^\circ}\right)\sin\delta\mathrm{N}\\ &+\nu\rho\sin(l-\mathrm{N})\cos f\,.\,a_0[\sin\left(\mathrm{J}+\frac{\delta\mathrm{J}}{\omega^\circ}\right)\cos\delta\mathrm{N}-\sin\mathrm{J}]\\ &+\frac{x''}{a_0}\delta a_0\end{aligned}$$

$$\begin{aligned}\delta y'' = &+\nu\sin g[\cos(\mathrm{G}'+v)+e\cos\mathrm{G}']\,.\,\kappa\sec\phi\,.\,\delta l_0\\ &-\nu\sin g[\cos(\mathrm{G}'+v)(\rho\cos v\cos\phi+e\cos\phi+\tan\tfrac{1}{2}\phi)+\cos\mathrm{G}']\,.\\ &\qquad a_0(\tan\phi+\delta e)\sin\delta(\mathrm{Q}+\mathrm{N})\\ &+\nu\sin g[\cos(\mathrm{G}'+v)\,.\,\rho\sin v\sec^2\phi-\sin\mathrm{G}']\,.\,a_0[(\tan\phi+\delta e)\cos\delta(\mathrm{Q}+\mathrm{N})\\ &\qquad -\tan\phi]\\ &-\nu\rho[\cos(l-\mathrm{N})\cos\delta+\tan\tfrac{1}{2}\mathrm{J}\sin(l-\mathrm{N}+a-\mathrm{N})\sin\delta]\,.\\ &\qquad a_0\left(\sin\mathrm{J}+\frac{\delta\mathrm{J}}{\omega^\circ}\right)\sin\delta\mathrm{N}\\ &+\nu\rho\sin(l-\mathrm{N})\,.\,\cos g\,.\,a_0[\left(\sin\mathrm{J}+\frac{\delta\mathrm{J}}{\omega^\circ}\right)\cos\delta\mathrm{N}-\sin\mathrm{J}]\\ &+\frac{y''}{a_0}\,.\,\delta a_0.\end{aligned}$$

If the assumed elements are circular, and if $\mathrm{F}_{,} = \mathrm{F}-\mathrm{N}$, $\mathrm{G}_{,} = \mathrm{G}-\mathrm{N}$, the coordinates become

$$x'' = a_0\nu\sin f\,.\,\sin(\mathrm{F}_{,}+l)$$
$$y'' = a_0\nu\sin g\,.\,\sin(\mathrm{G}_{,}+l)$$

and the equations of condition

$$
\begin{aligned}
\delta x'' = & +\nu \sin f \cos (F_{,}+l) . \kappa \delta l_0 \\
& -\nu \sin f [\cos (F_{,}+l) \cos l + \cos F_{,}] . a_0 e \sin (Q+N) \\
& +\nu \sin f [\cos (F_{,}+l) \sin l - \sin F_{,}] . a_0 e \cos (Q+N) \\
& +\nu \tan \tfrac{1}{2}J . \cos (l-N+\alpha-N) . a_0 \left(\sin J + \frac{\delta J}{\omega^{\circ}}\right) \sin \delta N \\
& +\nu \sin (l-N) \cos f . a_0 [\sin \left(J_0 + \frac{\delta J}{\omega^{\circ}}\right) \cos \delta N - \sin J] \\
& +\frac{x''}{a_0} . \delta a_0
\end{aligned}
$$

$$
\begin{aligned}
\delta y'' = & +\nu \sin g \cos (G_{,}+l) . \kappa \delta l_0 \\
& -\nu \sin g [\cos (G_{,}+l) \cos l + \cos G_{,}] . a_0 e \sin (Q+N) \\
& +\nu \sin g [\cos (G_{,}+l) \sin l - \sin G_{,}] . a_0 e \cos (Q+N) \\
& -\nu [\cos (l-N) \cos \delta + \tan \tfrac{1}{2}J \sin (l-N+\alpha-N) \sin \delta] . a_0 \sin \left(J + \frac{\delta J}{\omega^{\circ}}\right) \sin \delta N \\
& +\nu \rho \sin (l-N) \cos g . a_0 \sin [\left(J + \frac{\delta J}{\omega^{\circ}}\right) \cos \delta N - \sin J] \\
& +\frac{y''}{a_0} . \delta a_0
\end{aligned}
$$

The auxiliary angles are found by the formulæ

$$
\begin{aligned}
\sin f \sin E &= +\sin J \sin (\alpha - N) & \sin g \sin (G-F) &= -\sin (E+\delta) \\
\sin f \cos E &= +\cos J & \sin g \cos (G-F) &= -\cos (E+\delta) \cos f \\
\cos f &= -\sin J \cos (\alpha - N) & \cos g &= +\cos (E+\delta) \sin f \\
\sin f \sin F &= -\sin (\alpha - N) & & \\
\sin f \cos F &= +\cos (\alpha - N) \cos J & &
\end{aligned}
$$

or F − N by

$$\sin (F - N + \alpha) = \tan \tfrac{1}{2}J . \cos (\alpha - N) . \sin E.$$

The values of B and P used in the formulæ for polar-coordinates are

$$
\begin{aligned}
\cos B \sin P &= -\cos (\alpha - N) \sin J = \cos f \\
\cos B \cos P &= +\cos (E+\delta) \sin f = \cos g \\
\sin B &= -\sin (E+\delta) \sin f
\end{aligned}
$$

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## *On the Orbit of* OΣ 400. By J. E. Gore.

Some measures of this close binary star, made in 1885 with the 23-inch Refractor of the Princeton (U.S.A.) Observatory, and kindly sent me by Professor Young, show that the companion has described about 190° of its apparent ellipse since its discovery by O. Struve in 1844.

I have computed the orbit, and find the following provisional elements:—

*Elements of* OΣ 400.

| | |
|---|---|
| $P = 170{\cdot}37$ years | $\Omega = 146^{\circ}\ 20'$ |
| $T = 1882{\cdot}09$ | $\lambda = 43^{\circ}\ 30'$ |
| $e = 0{\cdot}669$ | $a = 0''{\cdot}59$ |
| $\gamma = 36^{\circ}\ 58'$ | $\mu = -2^{\circ}{\cdot}113$ |

The following table shows a comparison between these elements, and the observations used in the calculation of the orbit:—

| Epoch. | Observer. | $\theta_o$ | $\theta_c$ | $\theta_o-\theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o-\rho_c$ |
|---|---|---|---|---|---|---|---|
| 1844·83 | O. Struve | 336°·9 | 335°·23 | + 1°·67 | 0″·65 | 0″·74 | −0″·09 |
| 1845·69 | " | 334·7 | 334·57 | + 0·13 | 0·67 | 0·73 | −0·06 |
| 1846·68 | " | 333·1 | 333·73 | − 0·63 | 0·60 | 0·72 | −0·12 |
| 1851·81 | " | 328·8 | 329·32 | − 0·52 | 0·56 | 0·67 | −0·11 |
| 1853·23 | " | 324·6 | 327·70 | − 3·10 | 0·59 | 0·65 | −0·06 |
| 1853·89 | Dawes | 320·55 | 327·00 | − 6·45 | 0·65 | 0·64 | +0·01 |
| 1854·69 | O. Struve | 320·5 | 326·17 | − 5·67 | 0·62 | 0·63 | −0·01 |
| 1858·59 | " | 320·6 | 321·53 | − 0·93 | 0·62 | 0·57 | +0·05 |
| 1860·10 | " | 319·3 | 319·40 | − 0·10 | 0·62 | 0·55 | +0·07 |
| 1861·62 | " | 318·1 | 317·13 | + 0·97 | 0·62 | 0·53 | +0·09 |
| 1865·51 | Dembowski | 311·2 | 310·0 | + 1·20 | "difficillissima" | 0·45 | — |
| 1865·94 | " | 310·3 | 309·06 | + 1·24 | — | 0·44 | — |
| 1868·55 | " | 301·6 | 302·50 | − 0·90 | "difficile" "cert. oblunga" | 0·39 | — |
| 1870·51 | " | 302·0 | 296·27 | + 5·73 | "difficillissima" | 0·35 | — |
| 1871·57 | " | 300·4 | 292·1 | + 8·30 | "ovale" | 0·32 | — |
| 1872·57 | " | "Semplice?" | | | — | 0·30 | — |
| 1873·91 | " | 289·3 | 280·2 | + 9·10 | "oblunga?" "molta incerta" | 0·27 | — |
| 1874·50 | " | 287·8 | 276·3 | + 11·5 | "oblunga?" | 0·26 | — |
| 1875·67 | Schiaparelli | 267·9 | 267·70 | + 0·20 | 0·33 | 0·23 | +0·10 |
| 1877·59 | Dembowski | "Semplice; aria ottima" | | | — | 0·20 | — |
| 1878·647 | Burnham | "Single with all powers" of 18½-in. refractor | | | | 0·17 | — |
| 1885·715 | Young | 149·5 | 143·0 | + 6·5 | 0·3 "est" | 0·23 | — |
| 1885·731 | " | 139·5 | 143·0 | − 3·5 | >0·25 | 0·23 | > +0·02 |

Considering that the errors in the measures of so close a pair are necessarily considerable, the above comparison may be considered as fairly satisfactory.

The position of the binary is for 1880—

R.A. $20^h\ 6^m\ 14^s$

$+\ 43^\circ\ 35'$

Magnitudes, 7·3, 7·7, according to Burnham.

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*A Working Catalogue of "Red" Stars.* By G. F. Chambers.

The following catalogue is the outcome of many hundreds of observations, extending over (more particularly) a period of about seventeen years (1870–86), though not a few of the stars were examined in an unmethodical fashion during several years previous to 1870. Between 1870 and 1881 the telescope employed was a 4-inch Refractor by Cooke, but all the observations since 1884 have been made with a 6-inch Refractor by Grubb, almost always charged with an eyepiece of very low power, having a field of $1\frac{1}{4}^\circ$. The observations of colour cited with the name "Brodie" appended were made by my cousin, Mr. C. G. Brodie, of Fernhill, I.W., with an $8\frac{1}{2}$-inch Refractor, in the years 1884–86. He has seen most of the stars which I have observed, but I have quoted from his notes only, as a rule, in cases where we did not agree in our estimates of colour.

The existing catalogues of red stars from which contributions have been levied are the following: but I have not limited myself to these, having been in the habit for many years past of making notes of all red stars wheresoever mentioned:—

1804. Lalande, J. de. *Tables des Étoiles Rouges.* (*Connaissances des Temps*, An. xv. p. 378.)

1822. De Zach, Baron. *Étoiles Rouges.* (*Corresp. Ast.* vol. vii. p. 298.)

1847. Herschel, Sir J. *Ruby-coloured, or very Intense Red Stars.* (*Cape Observations*, p. 448.)

1866. Schjellerup, H. C. *Catalog der rothen, isolirten Sterne.* (*Ast. Nach.* vol. lxvii. No. 1591, June 18, 1866; Addenda, vol. lxviii. No. 1613, October 30, 1866.)

1872. Schmidt, J. F. J. *Verzeichniss rothgelber Sterne.* (*Ast. Nach.* vol. lxxx. No. 1902, September 5, 1872.)

1874. Schjellerup, H. C. *Zweiter Catalog der rothen, isolirten Sterne.* (*Vierteljahrsschrift der Astronomischen Gesellschaft*, vol. ix.)

1876. Burnham, S. W. *Catalogue of Red Double Stars.* (*Month. Not.* vol. xxxvi. p. 331, 1876.)

1877. Birmingham, J. *Observations and Catalogue of Red Stars.* (*Trans. Roy. Irish Acad.* vol. xxvi. p. 249, 1877.)

1877. Fearnley. *Des Étoiles colorées.* (*Ast. Nach.* vol. lxxxix. No. 2121, March 27, 1877.)

1879. LINDEMANN, E. *Verzeichniss von 42 neuen rothen Sternen.*
(*Bulletin de l'Acad. de St.-Pétersbourg*, vol. xxv. p. 155.)

1882. LINDEMANN, E. *Zweites Verzeichniss neuer rother Sternen.*
(*Bulletin de l'Acad. de St.-Pétersbourg*, vol. xxviii. p. 278.)

1885. ESPIN, Rev. T. E. *Some New Red Stars.*
(*Journal of Liverpool Ast. Soc.* vol. iii. p. 82, March 1885.)

1886. ESPIN, Rev. T. E. *Some New Red and Orange-red Stars.*
(*Month. Not. R.A.S.* vol. xlvi. p. 293, March 1886.)

This catalogue makes no pretence to being exhaustive; it must not be regarded as more than it professes to be, namely, a working list of the best of the red stars, almost always excluding known variables, many of which are notoriously red in colour. My reason for excluding known variables was this: their inclusion would have been a trap to observers using this list for the purpose for which alone it is designed, namely, to facilitate the study of any red stars which are always within reach of their instruments (regard being had to the season of the year and the latitude of the place of observation).

And in another senso this catalogue is not exhaustive; it only includes stars of decided colour and not less than 8½ magnitude. It may be that my eyes are not so sensitive to red hues as many other eyes are, but I certainly have often considered that many of my predecessors in the observation of red stars have greatly exaggerated the colours they have ascribed to particular objects. Taking the so-called "red" stars all round, my opinion is that a more generally accurate generic term for them would be "orange" stars, and that very few indeed rise to real "red," and that less than a dozen can be truly termed "carmine" or "ruby." These remarks seem requisite by way of caution in order to guard inexperienced observers from being disappointed when they come to examine for themselves stars described by Sir W. Herschel, Sir J. Herschel, Schmidt, and others, as "red" or "very red." There can be no doubt that these observers saw many stars to possess a redder tinge than they have since been found to exhibit. This may have been in the case of the Herschels some effect of their metallic mirrors, or of their eyesight, or may have been due to both causes combined; and, speaking generally, it may be said that the vast majority of the stars here catalogued are "orange" more than anything else. I would for this purpose define as "orange" the colour exhibited by the gilding inside articles of silver plate newly gilt.

A few, and only a few, explanations are requisite as to the principles on which the catalogue has been constructed. In column 1 one asterisk indicates objects of particular interest; two asterisks objects of very special and remarkable interest.

Column 2 gives the progressive numbers, if any, from Birmingham's catalogue. The places in columns 4 and 5 have been taken from the best authorities available, brought up to 1890. I have freely consulted the catalogues of Stone and Yarnall, and the Armagh catalogue, and the two Radcliffe catalogues, besides Birmingham's. The places of such of the stars as are to be found in the *Nautical Almanac* for 1890, or the *American Ephemeris* for 1889, are taken from those works respectively. Espin's places are as given by him, but brought up from 1885 to 1890. As, however, he only quotes the *Durchmusterung* to the nearest minute of Right Ascension and Declination, my 1890 places of his stars will be less exact than in the case of all the other stars. The magnitudes in column 6 are in all cases from Pickering's *Harvard Photometry*, where the star was to be found in that important and interesting record; one of the most valuable contributions to practical astronomy that has appeared for many years. The magnitudes of many of the remaining stars have been determined by Mr. C. G. Brodie by Dawes's method. In the column headed "Colour; Remarks" the information given within inverted commas has been generally taken from published sources, although the authority is not in all cases mentioned. All other details not in inverted commas reproduce the results of my own original work. The stars examined by myself amount to 589, out of a total of 719, being virtually nearly all those visible in England.

It would not be difficult to offer many interesting and suggestive reflections as the result of a prolonged study of the red stars; but one would soon be apt to drift away into speculations, which, however attractive to some minds, would not only be mere speculations, but would relate to matters quite beyond the domain of astronomy proper. I will therefore here only record the well-known facts that many of the stars certainly variable are red, and that many of the red stars have, since they were first noted as such, been found to be variable. The instances that could be cited in support of these statements are very numerous, and it is quite impossible for the coincidence between the redness of the colour and the variability of the light of several hundred stars to be accidental. What it means I do not presume to suggest. Amongst observers who have paid much attention to the colours of stars a foremost place must be given to the late Mr. J. Birmingham, of Tuam, whose labours in the matter of red stars added much to our knowledge of stellar colours. It was he who remarked that "a space of the heavens, including the Milky Way, between Aquila, Lyra, and Cygnus, seems so peculiarly favoured by red and orange stars that it might not inaptly be called 'the red region,' or 'the red region of Cygnus'; and, although the chances of finding a star of any stated colour must, of course, be greater among the countless multitudes of the Milky Way than elsewhere, still its other portions visible in this latitude show no such special richness in red stars."

One other remark of Birmingham's will be useful in this

place: "The red stars seem as liable to change of tint as to change of magnitude; and, although modifications of colour may have been remarked without any striking change of size, still I have observed that as a red variable increases it grows paler, and that it reddens deeper towards the minimum. Schmidt has made the same observation, and it well accords with the fact that all the very red stars are telescopic, and none of them visible to the naked eye. This is noteworthy, and seems difficult of explanation; but the cause, as I would suggest, may be found in the quality of light received from the object. As we do not see the stars by their discs, but by the amount of their light, according to apparent magnitude, it seems evident that the very red stars, shining with only a part of the components of white light, must appear less bright than the white stars, and seem therefore generally small. According to this view, it might be assumed that the few naked eye reddish stars would appear larger if white; so that Aldebaran, Betelgeuse, &c., if of that colour, might be rivals of Sirius. The redness of a star has given rise to the singular conceit that it shows a cooling down, or, as we might say, an approach to a final snuffing out of the luminary; but one might think that the fact of periodic variation of tint in many of the red stars ought to go far in disproving this proposition."

The reason why I have not included stars below the 9th magnitude is that where one is dealing with a star which is near the *minimum visibile* of a telescope estimations of colour are apt to become very imaginary in many cases. I say this without any desire to impute bad faith to an observer who might talk about "magnitude 13, colour red"; but I nevertheless should view his chromatic notions with a certain amount of distrust. I do not believe that it is, as a rule, possible to assign colour to stars of the 12th or lesser magnitudes, except a very large telescope indeed happens to be employed in viewing them.

The question has often been discussed as to how far flat surface diagrams of colour are of any use as standards of comparison for coloured stars. For my part I am disposed to question their usefulness, notwithstanding that I caused Smyth's well-known diagram of coloured discs to be reproduced for the new edition of the *Cycle of Celestial Objects*. I have often thought of trying whether a series of transparent discs of coloured glass, arranged in gradations of colour, and mounted in a frame sufficiently portable to be held in the hand by the observer whilst his eye is looking through the telescope, might not be used for comparisons of star colours. Probably the chief difficulty would be the obtaining of a sufficiently pure white light wherewith to illuminate the discs. If this were got over by the use of electricity or otherwise, I think such an apparatus might be effective and trustworthy, whilst it need not be very expensive nor very cumbersome.

The notes bearing the names of Bellamy and Robinson were sent to me in MS. by Mr. E. J. Stone, Director of the Radcliffe Observatory, Oxford.

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 1 | 1 | — Cassiopeiæ | 0 3 38 | +63 20·4 | 9 | Reddish. |
| 2 | | Cassiopeiæ | 0 9 5 | +65 29·8 | 8½ | Reddish. |
| 3 | 3 | ι Ceti | 0 13 49 | − 9 26·0 | 3½ | Golden yellow. |
| *4 | 4 | — Andromedæ | 0 14 5 | +44 5·9 | 8 | Fine fiery red. |
| 5 | | — Cassiopeiæ | 0 29 9 | +67 19·2 | 6¾ | Pale red. |
| 6 | | — Cassiopeiæ | 0 31 21 | +67 2·2 | 7¼ | Reddish. |
| **7 | 8 | δ Andromedæ | 0 33 26 | +30 15·6 | 3¼ | Golden yellow. |
| 8 | 9 | α Cassiopeiæ | 0 34 16 | +55 56·0 | 2¼ | Fine yellow. |
| 9 | 10 | β Ceti | 0 38 4 | −18 35·4 | 2 | Golden yellow. |
| 10 | | — Cassiopeiæ | 0 44 25 | +61 10·8 | 6¼ | Fiery orange. |
| 11 | | — Cassiopeiæ | 0 46 18 | +69 21·9 | 7½ | Orange. |
| 12 | 11 | — Cassiopeiæ | 0 50 59 | +67 5·9 | 8¾ | Reddish. |
| 13 | 12 | 2 Ursæ Minoris | 0 53 39 | +85 39·1 | 5 | Golden yellow. |
| 14 | 15 | 239 Groom. Cassiopeiæ | 1 0 36 | +52 54·5 | 6¼ | Pale orange. |
| **15 | 16 | η Ceti | 1 3 3 | −10 45·8 | 3½ | Fine golden yellow. "? Var." |
| 16 | 17 | β Andromedæ | 1 3 34 | +35 2·2 | 2¼ | Red. |
| ***17 | 18 | — Piscium | 1 10 4 | +25 11·2 | 7 | Fiery red. |
| 18 | 20 | — Andromedæ | 1 11 26 | +47 7·1 | 7 | Slight tinge of red. |
| 19 | 23 | — Cassiopeiæ | 1 20 3 | +65 30·4 | 7 | Pale red. |
| 20 | 24 | R Sculptoris | 1 21 55 | −33 7·3 | 6 | "Orange red" (J. Herschel). "Brilliant scarlet" (Gould). |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 21 | | 36 Espin Persei | 1 26 1 | +57 49·7 | 6 | Deep orange. |
| 22 | 26 | — Cassiopeiæ | 1 26 11 | +60 5·3 | 9 | Decided red, especially in contrast with neighbouring stars. Cl. = 103 M. |
| 23 | 28 | α Eridani | 1 33 36 | −57 47·7 | 1 | "Red." |
| **24 | 29 | ν Piscium | 1 35 42 | + 4 55·8 | 5 | Orange. |
| 25 | 30 | — Andromedæ | 1 36 55 | +50 3·7 | 7½ | Decided red. |
| ***26 | 31 | — Cassiopeiæ | 1 47 44 | +69 39·8 | 8 | Fiery red. |
| 27 | | 145 Espin Andromedæ | 1 52 6 | +44 52·6 | 8 | "Red" (Espin). |
| 28 | | — Ceti | 1 54 59 | + 9 9·2 | 6 | Reddish. |
| 29 | 33 | — Persei | 1 55 46 | +54 41·7 | 8 | Pale red. |
| 30 | 34 | γ Andromedæ | 1 57 8 | +41 48·1 | 2¼ | Golden yellow. |
| ***31 | 35 | α Arietis | 2 0 58 | +22 56·5 | 2 | Golden yellow. |
| 32 | 36 | — Ceti | 2 1 8 | + 0 55·2 | 8 | Slightly tinged. |
| 33 | 37 | 60 Andromedæ | 2 6 19 | +43 42·9 | 5 | Pale orange. |
| 34 | 39 | — Andromedæ | 2 11 8 | +44 41·9 | 8½ | Reddish. |
| 35 | 40 | ο Ceti | 2 13 47 | − 3 28·7 | Var. | Fiery red when approaching max. |
| 36 | 41 | — Persei | 2 14 38 | +56 37·9 | 9 | Fiery red; about midway between the clusters 33 and 34 ℌ VI. |
| 37 | | 65 Andromedæ | 2 18 17 | +49 46·7 | 5 | Good orange. |
| 38 | 45 | Arg. + 65 : 280 Cassiopeiæ | 2 28 43 | +65 16·5 | 6 | Deep orange. |
| 39 | | 15 Trianguli | 2 29 6 | +34 12·5 | Var. 5-8 | Reddish orange. |
| 40 | 46 | — Andromedæ | 2 30 26 | +56 35·6 | 8 | Pale red. |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 41 | 47 | 855 Weisse Triang. | 2 36 37 | +31 57·5 | 7½ | Red; neb. h 257 *p* (D'Arrest). |
| 42 | 49 | η Persei | 2 42 40 | +55 26·3 | 4 | Orange. |
| 43 | 50 | 5172 Lal. Persei | 2 43 30 | +57 52·6 | 7⅓ | Red. |
| 44 | 51 | — Cassiopeiæ | 2 47 23 | +63 52·7 | 6½ | Deep orange. |
| 45 | 52 | α Ceti | 2 56 31 | + 3 39·5 | 2¾ | Decided orange. "Orange red" (Robinson). |
| 46 | 56 | ω Persei | 3 4 11 | +39 11·6 | 4¾ | Reddish yellow. |
| 47 | 57 | — Persei | 3 4 54 | +47 18·6 | 7 | Pale red; 2 small red stars in the field *sf.* |
| 48 | 59 | 1014 B. A. C. Horologii | 3 9 46 | −57 44·0 | 7 | "Red." |
| 49 | 58 | 6048 Lal. Eridani | 3 10 11 | − 9 10·6 | 7 | Reddish; *p* ζ Erid. 18ˢ, and 4′ to the N. |
| 50 | 60 | W. B. III. 152 Eridani | 3 10 55 | − 6 7·9 | 7 | "Reddish orange." "Ruddy" (Robinson). |
| 51 | | ο Tauri | 3 18 53 | + 8 38·5 | 3½ | Orange. "Red" (*Uran. Arg.*). |
| 52 | 61 | Arg. + 54 : 685 Camelop. | 3 21 49 | +55 0·3 | 7½ | Pale red. |
| 53 | 62 | σ Persei | 3 22 49 | +47 36·9 | 4½ | Pale orange; contrasts well with white stars near. |
| 54 | | Arg. + 79 : 110 Camelop. | 3 32 20 | +79 58·4 | 7¾ | "Red' (Espin). |
| *55 | 65 | — Camelopardi | 3 32 21 | +62 17·4 | 7 | Pale crimson. |
| 56 | 66 | — Tauri | 3 36 2 | +14 26·4 | 8 | "Decided red." |
| 57 | 67 | — Persei | 3 37 44 | +53 33·6 | 8⅓ | Red. |
| 58 | 68 | 6921 Lal. Eridani | 3 38 28 | − 9 57·3 | 8 | Reddish. ? Mag. |
| 59 | 69 | 121 P. III. Camelop. | 3 39 17 | +65 10·9 | 6 | Deep orange. Mag. 4·75 (*Uran. Oxon.*). |
| 60 | 70 | π Eridani | 3 40 56 | −12 26·8 | 4½ | Reddish orange. |
| 61 | | 42 Espin Tauri | 3 41 29 | +24 38·9 | 7 | Reddish orange. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 62 | 71 | 1204 B. A. C. Camelop. | 3 47 43 | +60 47·3 | 5¼ | Pale orange. |
| 63 | | γ Hydri. | 3 48 57 | −74 34·5 | 3½ | "Deep yellow" (Williams). |
| 64 | 72 | 7272 Lal. Eridani | 3 49 53 | −15 13·8 | 7 | Orange; a larger star of the same colour *p*. |
| 65 | | $\gamma^1$ Eridani | 3 52 53 | −13 49·3 | 3 | Reddish orange. "Reddish" (Robinson). |
| 66 | | 220 P. III. Tauri | 3 55 45 | + 9 41·4 | 6 | Very pale orange. "Red" (*Uran. Arg.*) |
| 67 | | Arg. +61 : 667 Camelop. | 3 56 20 | +61 29·6 | 7½ | "Red" (Espin). |
| 68 | | 45 Espin Tauri | 3 58 10 | +12 12·0 | 7¾ | Reddish. |
| 69 | | γ Reticuli | 3 59 17 | −62 28·0 | 5 | "Deep yellow" (Williams). |
| 70 | | Arg. +32 : 743 Persei | 4 5 59 | +32 14·8 | 7 | Fiery orange. |
| 71 | | 47 Tauri | 4 7 57 | + 8 59·1 | 5 | Pale orange. "Red" (*Uran. Arg.*) |
| 72 | | 19 P. IV. Tauri | 4 8 51 | + 9 43·8 | 5¼ | Very pale orange. "Red" (*Uran. Arg.*) |
| 73 | 73 | 8154 Lal. Eridani | 4 15 14 | − 6 30·4 | 6½ | Pale orange. |
| 74 | 74 | 1342 B.A.C. Tauri | 4 15 54 | +20 33·4 | 6½ | Fiery orange. |
| 75 | | 47 Espin Persei | 4 17 4 | +34 59·4 | 7½ | Red. |
| 76 | | 45 Eridani | 4 26 15 | − 0 17·0 | 5 | Deep orange. "Red" (*Uran. Arg.*) |
| 77 | 79 | 8623 Lal. Eridani | 4 28 10 | −11 1·2 | 6½ | Reddish. |
| *78 | | 47 Eridani | 4 28 53 | − 8 27·5 | 5½ | Reddish orange. |
| 79 | 80 | ε (58) Persei | 4 29 3 | +41 2·2 | 4½ | Golden. |
| 80 | | W.B. IV. 585 Eridani | 4 29 8 | − 9 10·3 | 6 | Fiery red. "Red" (*Uran. Arg.*) |
| **81 | 81 | α Tauri | 4 29 36 | +16 17·2 | 1 | Deep reddish orange. |
| 82 | | 146 Espin Aurigæ | 4 37 27 | +43 34·7 | 8 | "Red" (Espin). |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 83 | 82 | — Aurigæ | 4 38 7 | +32 43·2 | $8\frac{3}{4}$ | Pale crimson; an orange star *p.* |
| 84 | | 2 Espin Aurigæ | 4 38 38 | +32 14·7 | $8\frac{1}{2}$ | Red. |
| *85 | 83 | 1457 B.A.C. Camelop. | 4 39 50 | +67 58·4 | 7 | Fiery red. |
| 86 | | 147 Espin Aurigæ | 4 41 56 | +34 48·4 | 8 | "Red" (Espin). |
| *87 | 85 | — Aurigæ | 4 44 37 | +28 20·2 | 8 | Unmistakably crimson. |
| 88 | | 148 Espin Aurigæ | 4 45 20 | +38 19·0 | $8\frac{1}{4}$ | "Very red" (Espin). |
| 89 | 87 | o¹ Orionis | 4 46 19 | +14 4·2 | $5\frac{1}{3}$ | Reddish orange. |
| 90 | | 149 Espin | 4 47 12 | +22 35·7 | 9 | "Very red" (Espin). |
| *91 | 88 | 5 Orionis | 4 47 38 | + 2 19·5 | $5\frac{3}{4}$ | Deep orange. "Probably var." |
| 92 | 89 | 236 P. IV. Orionis | 4 49 51 | + 7 36·0 | 6 | Deep golden yellow. "Orange red" (Brodie). Oxford R.A. = $4^h$ $48{\cdot}9^m$. |
| 93 | 91 | 6 Aurigæ | 4 52 49 | +39 29·5 | $6\frac{1}{3}$ | Red. |
| 94 | | 3 Espin Aurigæ | 4 53 3 | +40 4·6 | $7\frac{1}{2}$ | Fiery red. |
| 95 | | — Orionis | 4 53 14 | +12 40·0 | $8\frac{3}{4}$ | Decided red. Position approximate. |
| 96 | | 4 Espin Aurigæ | 4 53 44 | +40 22·4 | 8 | Reddish. |
| **97 | 94 | R Leporis | 4 54 36 | −14 58·2 | var. | Decided crimson. |
| 98 | 93 | ζ Aurigæ | 4 54 47 | +40 54·8 | 4 | Fine deep orange. "Slightly orange" (*Uran. Oxon.*). |
| 99 | | 150 Espin Aurigæ | 4 55 50 | +38 54·8 | $8\frac{1}{2}$ | "Very red" (Espin). |
| 100 | 95 | 276 P. IV. Orionis | 4 56 11 | + 0 33·6 | $6\frac{1}{4}$ | Pale orange. "? Var." |
| 101 | | 151 Espin Aurigæ | 4 59 8 | +34 42·3 | $8\frac{3}{4}$ | "Red" (Espin). |
| 102 | 96 | 899 H.P. Orionis | 4 59 43 | + 1 1·6 | 7 | Intense fiery red. |

| Number. G.F.C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 103 | 97 | ε Leporis | 5 0 48 | −22 31·1 | 3¼ | Reddish orange. "? Var." |
| 104 | 98 | — Orionis | 5 0 57 | + 0 24·2 | 9 | Decided red. |
| 105 | | 152 Espin Aurigæ | 5 4 15 | +43 34·5 | 8 | "Red" (Espin). |
| 106 | 99 | — Orionis | 5 4 24 | − 5 39·4 | 8 | Full red. |
| 107 | 100 | 9744 Lal. Orionis | 5 4 26 | − 0 42·1 | 6½ | Golden yellow. |
| *108 | | — Leporis | 5 6 38 | −12 1·2 | 7½ | Deep red. |
| 109 | 102 | Arg. −0 : 890 Orionis | 5 9 1 | − 0 41·2 | 7 | Pale orange. |
| 110 | | 5 Espin Aurigæ | 5 10 59 | +40 20·6 | 7 | Reddish orange. |
| *111 | | Arg. +40 : 1245 Aurigæ | 5 11 12 | +40 58·7 | 7½ | Fiery red. |
| 112 | | 50 Espin Aurigæ | 5 11 49 | +35 40·3 | 8½ | Fiery red. |
| 113 | 103 | — Aurigæ | 5 12 30 | +39 12·2 | 8 | Pale red. |
| 114 | | 51 Espin Orionis | 5 12 44 | − 8 21·9 | 8½ | Deep orange. |
| 115 | | W.B. V. 266 Aurigæ | 5 12 51 | +41 0·3 | 5¼ | Orange. "Slightly red" (*Uran. Oxon.*). |
| 116 | 104 | 9919 Lal. Aurigæ | 5 13 33 | +34 9·2 | 8½ | Red. "Reddish" (Brodie). |
| 117 | | 154 Espin Aurigæ | 5 14 43 | +32 23·4 | 9 | "Very red" (Espin). |
| 118 | 106 | 61 P.V. Orionis | 5 16 27 | + 3 28·0 | 8 | Red. |
| 119 | 107 | — Orionis | 5 18 1 | − 9 25·9 | 8½ | Reddish. ? Var. in colour. |
| *120 | | 53 Espin Orionis | 5 19 50 | −10 26·9 | 6 | Reddish orange. |
| *121 | | 52 Espin Aurigæ | 5 20 7 | +29 49·5 | 8 | Almost pale ruby. |
| 122 | | — Aurigæ | 5 20 38 | +35 13·3 | 7 | Good orange. In cl. 39 Ħ VII. |
| 123 | | 6 Espin Aurigæ | 5 22 39 | +40 25·5 | 7½ | Orange. |

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|---|---|---|---|---|---|---|
| 124 | 109 | S Orionis | 5 23 34 | − 4 47·0 | var. | Reddish. In centre of small equilat. triangle of 3 stars. |
| 125 | 110 | 31 Orionis | 5 23 59 | − 1 10·8 | 5–6 | Deep orange. "Var." |
| 126 | 111 | 119 Tauri | 5 25 47 | +18 30·7 | 4½ | Pale red. "Good orange" (Brodie). |
| 127 | | 7 Espin Aurigæ | 5 26 31 | +41 2·3 | 7½ | Reddish. |
| 128 | | 54 Espin Aurigæ | 5 26 31 | +32 40·0 | 7 | Reddish orange; blue star 6½ mag. near. |
| 129 | | 10426 Lal. Orionis | 5 26 59 | − 0 3·8 | 8 | Decided red. |
| 130 | | 156 Espin Orionis | 5 27 16 | + 7 3·6 | 7¾ | "Very red" (Espin). |
| 131 | | — Tauri | 5 28 3 | +25 49·1 | 8½ | Red. |
| 132 | | 10483 Lal. Orionis | 5 28 29 | − 1 32·4 | 7 | Fiery red. |
| 133 | 113 | $\phi^2$ Orionis | 5 30 51 | + 9 14·1 | 4½ | Pale orange. |
| 134 | 114 | — Orionis | 5 30 58 | +10 57·9 | 7 | Reddish orange. |
| *135 | | 124 Tauri | 5 32 34 | +23 15·5 | 7½ | Quadruple star; A red. |
| 136 | | $\beta$ Doradûs | 5 33 26 | −62 33·7 | 3½ | Reddish yellow (Williams). |
| 137 | | 157 Espin Aurigæ | 5 33 37 | +31 51·4 | 6½ | "Orange red" (Espin). |
| *138 | | Arg. + 31 : 1058 Aurigæ | 5 34 59 | +31 49·1 | 8½ | Fiery red. |
| 139 | 117 | 10743 Lal. Orionis | 5 35 29 | − 3 54·0 | 8 | Reddish. |
| 140 | 119 | 51 Orionis | 5 36 48 | + 1 25·3 | 5¼ | Golden yellow. "Slightly red" (*Uran. Oxon.*). |
| 141 | 120 | — Tauri | 5 38 30 | +24 22·3 | 8½ | Decided red. ? Var. |
| 142 | | 55 Espin Aurigæ | 5 38 41 | +50 2·5 | 7 | Reddish orange. |
| 143 | | — Aurigæ | 5 39 5 | +30 39·4 | 7 | Good red. |
| 144 | 121 | — Geminorum | 5 39 6 | +20 38·4 | 7½ | Good red. "Deep orange red" (Brodie). "? Var." |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 145 | 124 | — Pictoris | 5 40 8 | −46 30·5 | 8 | "Vivid red" (J. Herschel). |
| 146 | | 56 Espin Aurigæ | 5 40 33 | +44 48·0 | 9 | Red. |
| 147 | | 57 Espin Aurigæ | 5 44 18 | +32 5·8 | 6½ | Fiery red. Near neb. 37 M. |
| 148 | | 11061 Lal. Orionis | 5 44 22 | + 4 23·9 | 6 | Deep orange. "Red" (*Uran. Arg.*). |
| 149 | | Arg. + 32 : 1118 Aurigæ | 5 46 6 | +32 9·3 | 8½ | Fiery red. |
| 150 | | 11 Espin Aurigæ | 5 46 19 | +40 21·8 | 8 | Reddish. |
| 151 | | 58 Espin Aurigæ | 5 46 42 | +53 26·2 | 8 | Red. |
| 152 | | 56 Orionis | 5 46 44 | + 1 49·7 | 5 | Reddish orange. "Red" (*Uran. Arg.*). |
| 153 | 126 | Arg. + 10 : 927 Orionis | 5 48 7 | +10 33·6 | 6½ | Golden yellow. |
| 154 | | Arg. + 20 : 1171 Orionis | 5 49 5 | +20 26·9 | 8 | Reddish orange. |
| 155 | 127 | α Orionis | 5 49 13 | + 7 23·1 | 1 | Reddish orange. |
| 156 | | Gore's *nova* Orionis | 5 49 17 | +20 9·6 | 6½ | Fiery red. "Very red" (Robinson). |
| 157 | 129 | δ Aurigæ | 5 50 28 | +54 16·7 | 3¾ | Lemon yellow. |
| 158 | 130 | π Aurigæ | 5 51 45 | +45 55·7 | 4½ | Reddish orange. "Pale orange" (Brodie). |
| 159 | 133 | 11451 Lal. Orionis | 5 56 43 | − 5 8·2 | 7 | Reddish yellow. "Pale yellow" (Brodie). |
| 160 | | 13 Espin Aurigæ | 6 0 5 | − 5 51·0 | 7½ | Reddish orange. |
| 161 | | 158 Espin Aurigæ | 6 1 57 | +47 43·1 | 8 | "Red" (Espin). |
| *162 | 135 | 11684 Lal. Geminorum | 6 4 3 | +26 2·3 | 7½ | Good red. |
| 163 | | 14 Espin Aurigæ | 6 4 56 | +32 43·3 | 6 | Reddish. |
| 164 | 136 | Arg. + 21 : 1146 Geminorum | 6 5 14 | +21 53·6 | 7 | Pale red. |
| 165 | 137 | Arg. + 22 : 1220 Geminorum | 6 5 39 | +22 55·8 | 7 | Red. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 166 | | 15 Espin Aurigæ | 6 6 48 | +33 16·3 | 7 | Reddish orange. |
| 167 | 139 | η Geminorum | 6 8 14 | +22 32·3 | $3\frac{1}{2}$ | Reddish yellow. |
| 168 | 141 | Arg. + 39 : 1576 Aurigæ | 6 9 3 | +39 30·6 | $7\frac{1}{2}$ | Pale red. "? Var." |
| 169 | 140 | 5 Monocerotis | 6 9 30 | − 6 14·4 | $4\frac{1}{4}$ | Pale orange. |
| 170 | | 16 Espin Aurigæ | 6 9 52 | +39 53·7 | 7 | Reddish. |
| 171 | | 17 Espin Aurigæ | 6 10 2 | +40 24·8 | $8\frac{1}{2}$ | Orange. |
| 172 | | 18 Espin Aurigæ | 6 10 6 | +39 30·6 | 7 | Deep red. |
| 173 | | 62 Espin Aurigæ | 6 10 14 | +33 14·8 | 9 | Very red. |
| 174 | | 2029 B.A.C. Geminorum | 6 12 42 | +23 19·1 | 7 | Pale orange. "Magnificent spectrum." |
| 175 | | 1183 H.P. Canis Majoris | 6 12 48 | −16 46·3 | 5 | Red. |
| 176 | 142 | 12057 Lal. Orionis | 6 13 47 | +14 41·7 | 6 | Reddish yellow. |
| 177 | | 12104 Lal. Orionis | 6 14 29 | − 2 53·2 | 5 | Deep orange. "? Var." "Yellowish red" (Wickham). |
| 178 | | 160 Espin Aurigæ | 6 15 24 | +47 43·0 | $8\frac{1}{2}$ | "Red and probably var." (Espin). |
| 179 | | 12169 Lal. Canis Majoris | 6 15 57 | −11 45·8 | 7 | Fiery red. "Red" (Robinson). |
| 180 | 143 | μ Geminorum | 6 16 18 | +22 34·1 | $3\frac{1}{4}$ | Reddish orange. |
| 181 | | 161 Espin Geminorum | 6 17 12 | +25 4·2 | 9 | "Very red" (Espin). |
| 182 | | 5 Lyncis | 6 17 12 | +58 28·7 | $5\frac{1}{2}$ | Orange. |
| 183 | | 3 Canis Majoris | 6 18 5 | −33 22·8 | 4 | "Rich orange yellow" (Tupman). |
| *184 | 144 | — Geminorum | 6 19 11 | +14 46·8 | 7 | Full deep orange. "? Var." "Yellowish" (Brodie). |
| 185 | 145 | — Canis Majoris | 6 19 16 | −26 59·6 | 8 | Pale crimson. "Intense ruby" (J. Herschel). "Orange red" (Brodie). |

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|---|---|---|---|---|---|---|
| 186 | | 12359 Lal. Monocerotis | 6 21 31 | − 4 23·7 | 7 | Deep orange. |
| 187 | 147 | — Monocerotis | 6 24 56 | − 2 56·8 | 8 | Orange, or slightly reddish. |
| 188 | | 12524 Lal. Canis Majoris | 6 25 25 | −19 8·1 | 6⅓ | Orange. |
| 189 | | 12545 Lal. Monocerotis | 6 26 50 | − 8 5·2 | 5⅓ | Reddish orange. "Red" (*Uran. Arg.*). |
| 190 | | 20 Espin Monocerotis | 6 28 19 | − 2 59·8 | 7⅓ | Orange. Position approximate. |
| **191 | 148 | 2139 B.A.C. Aurigæ | 6 28 59 | +38 32·0 | 6 | Deep fiery red. |
| 192 | | 165 Espin Monocerotis | 6 29 39 | − 1 22·7 | 8¼ | "Very red" (Espin). |
| 193 | | 21 Espin Aurigæ | 6 31 2 | +39 29·5 | 6½ | Reddish orange. |
| 194 | | $\nu^2$ Canis Majoris | 6 31 53 | −19 9·7 | 4 | Orange. "Red" (Robinson). |
| 195 | 150 | 2196 B.A.C. Puppis | 6 35 57 | −52 50·0 | 6 | "De color rojizo" (Moesta). |
| 196 | | 22 Espin Aurigæ | 6 36 33 | +40 44·2 | 7 | Double: A 8, pale orange; B 10, blue; dist. 30″. |
| 197 | 151 | 12907 Lal. Monocerotis | 6 36 41 | − 9 3·5 | 5½ | Pale orange. |
| 198 | 152 | $\epsilon$ Geminorum | 6 37 10 | +25 14·3 | 3¼ | Golden yellow. "? Var." |
| 199 | | 23 Espin Geminorum | 6 38 36 | +24 46·5 | 7½ | Fiery orange. |
| 200 | | 17 Monocerotis | 6 41 22 | + 8 9·4 | 5 | Reddish yellow. |
| 201 | 153 | — Canis Majoris | 6 42 18 | −20 37·8 | 8 | Pale red; near centre of cl. 41 M. |
| *202 | | 13100 Lal. Monocerotis | 6 42 22 | − 8 52·4 | 5½ | Reddish orange. |
| 203 | | Arg. + 61 : 915 Lyncis | 6 43 10 | +61 9·5 | 8 | "Reddish" (Espin). |
| 204 | 154 | 51 Cephei (Hev.) | 6 48 46 | +87 13·1 | 5¼ | Full orange. |
| 205 | 156 | $\theta$ Canis Majoris | 6 49 5 | −11 54·1 | 4¼ | Reddish orange. "Red" (Robinson). |
| 206 | 157 | $o^1$ Canis Majoris | 6 49 34 | −24 2·7 | 4 | Deep orange. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour ; Remarks. |
|---|---|---|---|---|---|---|
| 207 | 158 | μ Canis Majoris | 6 51 3 | −13 54·0 | 5¼ | Fiery red. |
| 208 | | Arg. −8 : 1650 Monocerotis | 6 52 49 | − 8 52·6 | 7 | "Orange red" (Espin). |
| 209 | 161 | 2289 B.A.C. Puppis | 6 53 20 | −48 34·0 | 5½ | "De color rojizo" (Moesta). |
| 210 | 160 | 1245 Groom. Camelopardi | 6 53 24 | +70 53·5 | 6½ | Pale red. |
| 211 | | 13627 Lal. Monocerotis | 6 56 32 | − 5 33·7 | 5⅓ | Good orange. "? Var." |
| 212 | | — Monocerotis | 6 56 45 | − 5 33·0 | 7 | Pale orange. |
| 213 | 162 | 22 Canis Majoris | 6 57 20 | −27 46·6 | 3½ | Fiery red. "Reddish" (Brodie). "? Var." |
| 214 | 163 | — Monocerotis | 6 57 40 | − 8 11·2 | 8 | Red. In cl. 50 M. "Reddish" (Brodie). |
| 215 | | $o^2$ Canis Majoris | 6 58 26 | −23 40·4 | 3 | Pale yellow. |
| **216 | 165 | — Monocerotis | 7 1 36 | − 7 23·4 | 8 | Crimson. |
| *217 | 166 | — Canis Majoris | 7 2 55 | −11 45·3 | 7½ | Decided red. |
| *218 | 167 | R Canis Minoris | 7 3 40 | +10 11·9 | 7–10 | Deep red. "Var." |
| 219 | | 2337 B.A.C. Geminorum | 7 3 43 | +13 44·3 | 6½ | Deep orange. |
| 220 | | δ Canis Majoris | 7 3 55 | −26 13·1 | 2 | Reddish yellow "Fine yellow" (Tupman). |
| 221 | 168 | 2326 B.A.C. Camelopardi | 7 7 56 | +82 37·4 | 5¼ | Reddish orange. |
| 222 | 170 | 14038 Lal. Geminorum | 7 8 59 | +22 9·6 | 7 | Orange, or pale red. |
| 223 | | 65 Espin Canis Majoris | 7 12 0 | −23 7·0 | 6½ | Wide pair. A 6½, orange ; B 7, blue. "A probably var." (Espin). |
| 224 | | 14184 Lal. Monocerotis | 7 12 9 | − 6 28·7 | 6½ | Reddish orange. |
| 225 | | $L^2$ Puppis | 7 10 10 | −44 27·7 | 5 | "Red and var." (*Uran. Arg.*). |
| 226 | 171 | π Puppis | 7 13 15 | −36 54·0 | 3 | "Beautiful orange" (Gore). "Very rich yellow" (Tupman). |

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|---|---|---|---|---|---|---|
| 227 | 172 | — Monocerotis | 7 15 45 | −10 10·9 | 8 | Orange. In cl. h. 443 |
| 228 | | 66 Aurigæ | 7 16 31 | +40 53·1 | 5½ | Pale orange. |
| 229 | 175 | — Canis Majoris | 7 18 28 | −25 33·0 | 7 | Red. |
| 230 | | η Canis Majoris | 7 19 44 | −29 5·3 | 2½ | Perhaps purplish. "? Purple" (Tupman). "Pale red" (Smyth). |
| 231 | | 171 Espin Lyncis | 7 20 10 | +46 11·4 | 8 | "Red" (Espin). |
| 232 | 176 | 14503 Lal. Canis Majoris | 7 21 2 | −20 44·1 | 8 | Red. |
| 233 | 178 | 14599 Lal. Monocerotis | 7 24 4 | −10 5·9 | 6 | Reddish orange. "? Var." |
| 234 | 179 | σ Argûs | 7 25 44 | −43 4·9 | 5 | "Red" (Schmidt). |
| *235 | | 14776 Lal. Puppis | 7 28 44 | −14 17·0 | 5 | Fiery red. |
| 236 | 181 | υ Geminorum | 7 29 9 | +27 8·7 | 4¼ | Orange. |
| 237 | | 25 Espin Lyncis | 7 29 38 | +40 15·8 | 7 | Reddish. The *p* star of a curious curve of 5 stars. |
| 238 | | 174 Espin Monocerotis | 7 30 44 | − 5 31·8 | 8 | "Red" (Espin). |
| 239 | | 175 Espin Canis Minoris | 7 30 44 | + 2 19·0 | 8¾ | "Red with blue *comes*" (Espin). |
| 240 | 182 | 1444 H. P. Geminorum | 7 34 20 | +23 17·3 | 6 | Fiery red. |
| 241 | | 14952 Lal. Puppis | 7 34 26 | −16 35·5 | 6 | Pale red. |
| 242 | | 26 Espin Canis Minoris | 7 34 55 | + 4 19·4 | 7 | Reddish orange. Position approximate. |
| 243 | 183 | 27 Espin Geminorum | 7 35 43 | +29 5·2 | 8 | Pale orange. |
| 244 | | γ Monocerotis | 7 36 0 | − 9 17·7 | 4½ | Lemon yellow. "Reddish" (Robinson). |
| 245 | | σ Geminorum | 7 36 26 | +29 9·2 | 4 | Pale orange; a small red star *p* 39ˢ. |
| 246 | 186 | 15018 Lal. Monocerotis | 7 37 4 | −10 37·4 | 7½ | Pale red. |

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|---|---|---|---|---|---|---|
| 247 | 187 | Arg. +5 : 1759 Canis Min. | 7 37 33 | + 5 12·3 | 7 | Pale red. |
| 248 | 188 | β Geminorum | 7 38 35 | +28 17·5 | 1 | Pale yellow. |
| 249 | 189 | c Puppis | 7 41 20 | −37 42·1 | 4½ | "Orange" (J. Herschel). The chief star in neb. h 3099. |
| 250 | | 28 Espin Lyncis | 7 42 43 | +40 2·9 | 7 | Pale red. |
| 251 | | 176 Espin Canis Minoris | 7 42 51 | + 5 42·0 | 9 | "Very red" (Espin). |
| 252 | | ξ Argûs | 7 44 40 | −24 35·0 | 3½ | Good orange. |
| 253 | 194 | — Velorum | 7 54 7 | −49 41·5 | 8 | "Brick red, inclining to orange" (J. Herschel). |
| 254 | 195 | — Carinæ | 7 56 16 | −60 31·2 | 8 | "Orange;" in neb. h 3111; "near it a ruddy star" (J. Herschel). |
| 255 | 196 | 2704 B.A.C. Lyncis | 8 1 2 | +58 34·7 | 6 | Orange. |
| *256 | | β Cancri | 8 10 33 | + 9 31·4 | 4 | Reddish yellow. |
| 257 | 201 | 2820 B.A.C. Puppis | 8 19 13 | −37 55·9 | 6 | "De color rojizo" (Moesta). |
| 258 | | ε Argûs | 8 20 15 | −59 9·3 | 2½ | "Yellow; orange" (Tupman). |
| 259 | | 72 P. VIII. Puppis | 8 20 18 | −23 41·4 | 5½ | Orange. "Orange" (Tupman). |
| 260 | 205 | 17091 Lal. Hydræ | 8 34 11 | −19 21·1 | 6½ | Red. |
| 261 | | 3449 Lac. Mali | 8 35 5 | −28 41·5 | 7 | "Orange" (Gore). ? Place. |
| 262 | 206 | Arg. 8952 Mali | 8 40 52 | −27 47·9 | 8½ | Full red. |
| 263 | 208 | — Puppis | 8 46 14 | −47 58·2 | 8½ | "Ruby-coloured" (J. Herschel). |
| 264 | 209 | 17497 Lal. Cancri | 8 47 4 | +19 44·3 | 8½ | Reddish. |
| *265 | 211 | 17576 Lal. Cancri | 8 49 11 | +17 39·0 | 7 | Pale crimson. "Rich orange red" (Brodie). |
| 266 | 212 | 60 Cancri | 8 49 56 | +12 2·8 | 6–8 | Reddish orange. "Probably var." |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 267 | 213 | 17624 Lal. Hydræ | 8 50 1 | −10 57·0 | 7½ | Pale red: a blue star with a companion follows. |
| 268 | | σ¹ Ursæ Majoris | 8 58 48 | +67 19·1 | 5¼ | Deep orange. |
| 269 | | ω Hydræ | 9 0 11 | + 5 31·8 | 5½ | Deep orange. "Red" (*Uran. Arg.*). |
| 270 | 217 | 3121 B.A.C. Mali (κ Pyxis) | 9 3 13 | −25 24·4 | 4¾ | Deep red. |
| 271 | | λ Argûs | 9 3 57 | −42 59·3 | 2½ | "Orange" (Tupman). "Blood red" (Pope). |
| 272 | 218 | Arg. +31 : 1946 Cancri | 9 4 3 | +31 24·9 | 6½ | Fiery red. "Pale orange" (Brodie). "? Var." |
| 273 | 219 | π² Cancri | 9 9 10 | +15 24·0 | 5¾ | Pale orange. |
| 274 | | *g* Carinæ | 9 13 5 | −57 4·9 | 4½ | "Deep orange red" (Tupman). |
| 275 | 220 | α (40) Lyncis | 9 14 21 | +34 51·4 | 3½ | Reddish orange; a small blue star, *nf*, 12ˢ. |
| 276 | 221 | Arg. +0 : 2499 Hydræ | 9 14 58 | + 0 38·2 | 7 | Reddish. |
| 277 | 223 | α Hydræ | 9 22 11 | − 8 10·9 | 2 | Reddish yellow. "Possibly var." |
| 278 | | 18688 Lal. Hydræ | 9 24 8 | +20 16·0 | 6¼ | Fiery red. "Red" (Bellamy). |
| 279 | | — Ursæ Majoris | 9 25 11 | +67 46·5 | 7 | Orange. ? var. in colour. Decl. approximate. |
| 280 | 224 | λ Leonis | 9 25 27 | +23 27·3 | 4½ | Reddish orange. "Slightly red" (*Uran. Oxon.*). |
| 281 | | N Velorum | 9 27 53 | −56 32·9 | 3¾ | "Very rich yellow" (Tupman). |
| 282 | 225 | — Carinæ | 9 29 28 | −62 18·5 | 8 | "Sanguine red" (J. Herschel). |
| 283 | 226 | ι Hydræ | 9 34 14 | − 0 38·7 | 4¼ | Orange. |
| 284 | | ε Leonis | 9 39 36 | +24 16·8 | 3 | Pale orange. |
| 285 | | *l* Carinæ | 9 41 13 | −62 0·0 | 4½ | "Yellow; orange" (Tupman). |
| 286 | 228 | R Leonis | 9 41 39 | +11 56·5 | 5–10 | Pale crimson. "Var." |
| 287 | 229 | Ö–A (2) 10163 Hydræ | 9 45 58 | −22 30·2 | 7 | Good red. "Distinctly red" (Bellamy). |

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|---|---|---|---|---|---|---|
| 288 | | 66 Espin Ursæ Majoris | 9 49 0 | +54 47·0 | 7 | Dark orange. =2412 Rad. |
| 289 | 230 | — Velorum | 9 50 57 | −41 4·0 | 7½ | "Scarlet" (J. Herschel). |
| 290 | | 29 Espin Leonis | 9 51 46 | + 8 53·3 | 7 | Reddish orange. |
| 291 | 231 | π Leonis | 9 54 24 | + 8 34·3 | 5 | Reddish orange. "Orange red" (Robinson). |
| 292 | | 19580 Lal. Sextantis | 9 55 25 | − 2 39·5 | 7 | Reddish. |
| 293 | 232 | — Carinæ | 9 56 25 | −59 41·9 | 8½ | "Scarlet" (J. Herschel). |
| 294 | | 19620 Lal. Hydræ | 9 56 38 | −23 16·5 | 7 | Reddish. |
| 295 | | 19627 Lal. Sextantis | 9 57 25 | − 5 5·0 | 7 | Reddish. |
| 296 | 233 | A (31) Leonis | 10 2 4 | +10 32·3 | 4½ | Orange. |
| 297 | 234 | 18 Sextantis | 10 5 29 | − 7 52·4 | 5¾ | Reddish orange. "Orange" (Robinson). "? var." |
| 298 | 235 | — Antliæ | 10 7 5 | −34 46·7 | 7 | "Scarlet" (J. Herschel). |
| 299 | 236 | — Carinæ | 10 10 39 | −60 8·4 | 9 | "Ruby red" (J. Herschel). |
| 300 | | 30 Espin Ursæ Majoris | 10 10 50 | +42 0·9 | 6½ | Fiery orange. "? var." |
| 301 | | *q* Carinæ | 10 13 24 | −60 47·0 | 4 | "Orange red" (Tupman). |
| 302 | 237 | γ Leonis | 10 13 54 | +20 23·8 | 2 | Pale orange. |
| 303 | | V Velorum | 10 15 29 | −54 28·6 | 5 | "Red" (Tupman). |
| 304 | 238 | μ Ursæ Majoris | 10 15 47 | +42 4·2 | 3 | Orange. |
| 305 | 239 | μ Hydræ | 10 20 46 | −16 16·5 | 4 | Reddish orange. |
| 306 | | *s* Carinæ | 10 23 50 | −58 10·6 | 4¼ | "Yellow; orange" (Tupman). |
| 307 | | 4367 Lac. Carinæ | 10 28 28 | −72 39·3 | 5½ | "Deep orange" (Tupman). |
| 308 | 240 | 3630 B.A.C. Antliæ | 10 30 20 | −38 59·9 | 6½ | "Orange; almost scarlet" (J. Herschel). |

| Number. G.F.C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 309 | 241 | $r$ Carinæ | 10 31 22 | −56 59·3 | $5\frac{1}{2}$ | "De color rojizo" (Moesta). "Orange red" (Tupman). |
| **310 | 242 | 3637 B.A.C Hydræ | 10 32 7 | −12 48·8 | $5\frac{1}{2}$ | Fiery red. "Var. beyond question" (Gould). |
| 311 | | $t^2$ Carinæ | 10 34 34 | −58 36·6 | 5 | "Deep orange red" (Tupman). |
| 312 | | — Ursæ Majoris | 10 37 26 | −67 9·3 | 6 | Good pale red. |
| 313 | | 4435 Lac. Carinæ | 10 38 25 | −58 38·4 | 6 | "Red" (Brisbane). |
| 314 | 245 | 4446 Lac. Carinæ | 10 39 21 | −59 59·4 | 6 | "Red" (Brisbane). "Deep orange red" (Tupman). |
| 315 | 247 | $\eta$ Argûs | 10 40 47 | −59 6·5 | 6 | "Orange" (Tupman). "Var." |
| 316 | | $\mu$ Argûs | 10 42 2 | −48 50·3 | 3 | "Very red" (Tupman). |
| 317 | | 20891 Lal. Sextantis | 10 45 30 | − 2 30·4 | $6\frac{1}{2}$ | Pale orange. |
| 318 | 248 | 20918 Lal. Hydræ | 10 46 16 | −20 40·1 | 7 | Pale crimson. "Very red" (Robinson). |
| 319 | | $u$ Carinæ | 10 49 1 | −58 16·1 | $4\frac{1}{2}$ | "Bright orange red" (Tupman). |
| 320 | | — Leonis | 10 50 | +22 58 | 7 | Orange. "Reddish yellow" (F. Brodie). Pos. approx. |
| 321 | | 31 Espin Leonis | 10 52 45 | +20 13·4 | 7 | Reddish. ? Decl. 1° too little. |
| 322 | 249 | 1917 H.P. Crateris | 10 54 5 | −15 45·8 | $6\frac{1}{4}$ | Reddish. |
| 323 | | $\alpha$ Crateris | 10 54 27 | −17 42·9 | $4\frac{1}{2}$ | Orange. "Red" (Robinson). |
| 324 | 250 | R Crateris | 10 55 8 | −17 37·6 | 8–9 | Orange. "Var." |
| 325 | 251 | 60 Leonis | 10 56 27 | +20 46·3 | $4\frac{1}{2}$ | Pale yellow. |
| 326 | 252 | $\alpha$ Ursæ Majoris | 10 56 56 | +62 20·7 | 2 | Pale orange. "Var. in colour and perhaps in mag." |
| 327 | 254 | $\psi$ Ursæ Majoris | 11 3 29 | +45 5·8 | 3 | Reddish. |
| 328 | | $x$ Carinæ | 11 3 53 | −58 22·7 | $4\frac{3}{4}$ | "Deep orange red" (Tupman). |
| 329 | 255 | — Chamæleontis | 11 5 30 | −81 11·5 | 8 | "Ruby" (J. Herschel). |

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|---|---|---|---|---|---|---|
| 330 | 256 | 72 Leonis | 11 9 21 | +23 41·7 | 5 | Reddish yellow. |
| 331 | 258 | 75 Leonis | 11 11 37 | + 2 37·0 | 5½ | Reddish orange. |
| **332 | 259 | ν Ursæ Majoris | 11 12 32 | +33 41·7 | 3¾ | Deep golden yellow. |
| 333 | | δ Crateris | 11 13 50 | −14 11·0 | 3½ | Reddish yellow. "Orange red" (Robinson). |
| 334 | 261 | 87 Leonis | 11 24 42 | − 2 23·7 | 5 | Orange. |
| 335 | 262 | λ Draconis | 11 24 52 | +69 56·3 | 4 | Orange. |
| 336 | | υ Leonis | 11 31 19 | − 0 13·0 | 4½ | Reddish yellow. |
| 337 | | ω Virginis | 11 32 47 | + 8 44·5 | 5½ | Orange. "Red" (*Uran. Arg.*). |
| 338 | | 22104 Lal. Crateris | 11 34 16 | −16 1·5 | 6 | Red. |
| 339 | 264 | -- Muscæ | 11 34 34 | −71 57·5 | 8½ | "Fine ruby" (J. Herschel). |
| 340 | 265 | 22122 Lal. Leonis | 11 35 29 | +25 51·5 | 8 | Reddish yellow. Decl. only approximate. |
| 341 | | 32 Espin Ursæ Majoris | 11 38 37 | +49 7·6 | 8 | Red. |
| 342 | 266 | χ Ursæ Majoris | 11 40 24 | +48 23·4 | 4 | Golden. |
| 343 | | 4809 Lac. Muscæ | 11 42 57 | −66 12·9 | 5 | "Red" (Tupman). |
| 344 | 268 | — Centauri | 11 44 51 | −56 34·0 | 8 | "Orange;" about 10′ N. of neb. h 3365 (J. Herschel). |
| 345 | 269 | 203 P. XI. Virginis | 11 52 30 | + 4 6·5 | 8 | Red. |
| 346 | 270 | 1845 Groom. Ursæ Minoris | 11 54 35 | +81 28·1 | 6 | Reddish. |
| 347 | | 5032 Lac. Crucis | 12 2 40 | −60 14·1 | 6 | "Red" (Stone). |
| *348 | 272 | ε Corvi | 12 4 28 | −22 0·5 | 3 | Reddish orange. "Reddish" (Robinson). "? Var." |
| 349 | | ε Muscæ | 12 11 38 | −67 20·9 | 5 | "Orange red" (Tupman). |
| 350 | | ε Crucis | 12 15 26 | −59 47·6 | 4 | "Orange" (Tupman). |

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|---|---|---|---|---|---|---|
| 351 | 276 | 17 Virginis | 12 16 57 | + 5 55·2 | 7 | Double, dist. 20″; A tinged; B red. |
| **352 | 277 | — Virginis | 12 19 38 | + 1 23·6 | 8¼ | Good crimson. "? Var." |
| 353 | | 71 Ursæ Majoris | 12 19 48 | +57 23·3 | 5½ | Good orange. |
| *354 | 279 | γ Comæ Berenicis | 12 21 27 | +28 52·9 | 4¾ | Deep golden yellow. |
| 355 | 280 | — Comæ Berenicis | 12 23 40 | +28 54·2 | 9 | Certainly red. "Reddish tinge" (Brodie). "Purple" (J. Herschel). |
| 356 | 281 | — Virginis | 12 24 44 | +5 1·3 | 8½ | Deep red. |
| 357 | 282 | γ Crucis | 12 25 3 | −56 29·6 | 2 | "Clear orange yellow" (Gould). |
| 358 | | 4 Draconis | 12 25 19 | −69 48·4 | 5¼ | Reddish orange. |
| 359 | | 23649 Lal. Virginis | 12 33 49 | − 5 29·7 | 6½ | Reddish. |
| 360 | 287 | 23736 Lal. Virginis | 12 38 3 | − 0 50·1 | 8½ | Reddish. |
| *361 | 290 | 4287 B.A.C. Can. Venat. | 12 39 57 | +46 2·4 | 5½ | Red. "Good orange" (Brodie). "Probably var." |
| 362 | 291 | — Crucis | 12 40 58 | −59 5·6 | 8½ | "Most intense blood red" (J. Herschel). |
| 363 | 295 | κ Crucis | 12 47 7 | −59 45·2 | 7 | In neb. h 3435; "central and largest star red." |
| 364 | | ψ Virginis | 12 48 38 | − 8 56·4 | 5 | "Red" (*Uran. Arg.*). |
| 365 | 297 | δ Virginis | 12 50 3 | + 3 59·7 | 3¾ | Lemon yellow. "Reddish yellow" (Robinson). |
| 366 | 298 | — Draconis | 12 52 5 | +66 35·3 | 7 | Red. |
| 367 | 299 | 24148 Lal. Comæ Berenicis | 12 52 40 | +18 21·6 | 8 | Reddish. "Red tinge" (Brodie). |
| 368 | | 1944 Groom. Draconis | 12 52 45 | +67 50·2 | 6½ | Orange. |
| 369 | 300 | 36 Comæ Berenicis | 12 53 30 | +18 0·1 | 5 | Reddish yellow. "Perhaps var." |
| 370 | | 9 Draconis | 12 55 57 | +67 11·5 | 5¼ | Good orange. ? Var. |

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|---|---|---|---|---|---|---|
| 371 | | 5460 Lac. Centauri | 13 10 8 | +44 7·4 | 7 | "Red" (Stone). |
| 372 | 302 | $\sigma$ Virginis | 13 12 3 | + 0 3·0 | 5 | Reddish yellow. |
| 373 | | 61 Virginis | 13 12 40 | −17 41·8 | 4¾ | Pale orange. |
| 374 | 303 | $\gamma$ Hydræ | 13 12 54 | −22 35·4 | 3½ | Pale orange. "Red" (Brodie). "Perhaps var." |
| 375 | | 24769 Lal. Virginis | 13 16 14 | −13 50·5 | 7 | Reddish tinge. |
| 376 | 304 | 4479 B.A.C. Canum Venat. | 13 18 54 | +37 36·3 | 6½ | Golden. |
| 377 | 306 | $i$ Virginis | 13 20 54 | −12 8·1 | 5½ | Reddish. "Yellowish red" (Brodie). |
| 378 | 309 | $l$ (74) Virginis | 13 26 14 | − 5 41·1 | 5 | Orange. "Red" (*Uran. Arg.*). |
| 379 | 311 | W.B. XIII. 596 Comæ Ber. | 13 31 48 | +25 10·2 | 6 | Orange tinge. |
| 380 | | 25213 Lal. Virginis | 13 34 2 | −15 53·3 | 6½ | Reddish. |
| 381 | 312 | 83 Ursæ Majoris | 13 36 34 | +55 14·3 | 4¾ | Golden. "? Var." |
| 382 | 313 | 7561 Stone Hydræ | 13 42 49 | −27 49·0 | 6½ | Red. "Splendid red." |
| 383 | | 25462 Lal. Virginis | 13 44 11 | −20 19·4 | 7 | Reddish. |
| 384 | 314 | $v$ Böotis | 13 44 11 | +16 20·6 | 4 | Orange red. "Orange" (Brodie). "Probably var." |
| 385 | 315 | $i$ (10) Draconis | 13 48 11 | +65 15·9 | 4¾ | Golden. "Slightly red" (*Uran. Oxon.*). |
| 386 | 316 | 3105 Rad. Canum Venat. | 13 48 29 | +40 52·8 | 7 | Orange. |
| 387 | 318 | $\pi$ Hydræ | 14 0 6 | −26 9·0 | 3½ | Deep orange. |
| 388 | | $\theta$ Centauri | 14 0 13 | −35 49·6 | 2 | "Pale orange?" (Tupman). |
| 389 | | 95 Virginis | 14 0 53 | − 8 47·3 | 5¾ | "Red" (*Uran. Arg.*). |
| 390 | 319 | — Centauri | 14 1 19 | −59 12·2 | 8 | "Double: both stars brick red" (J. Herschel). |
| 391 | 320 | 13 Böotis | 14 4 10 | +49 58·6 | 5½ | Reddish. |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| *392 | 321 | 4700 B.A.C. Virginis | 14 4 51 | −15 47·0 | 5¼ | Red. |
| 393 | 322 | κ Virginis | 14 7 1 | − 9 45·7 | 4¼ | Reddish. "Orange red" (Robinson). |
| 394 | 323 | — Centauri | 14 9 0 | −59 24·0 | 7½ | "Ruby or high orange" (J. Herschel). |
| 395 | 324 | 4 Ursæ Minoris | 14 9 17 | +78 3·9 | 5 | Orange. |
| 396 | 325 | 4732 Ursæ Minoris | 14 10 2 | +69 57·0 | 5¼ | Pale orange. |
| **397 | 326 | α Böotis | 14 10 39 | +19 45·3 | 1 | Golden yellow. |
| 398 | | — Virginis | 14 10 57 | −16 0·8 | 8¾ | Reddish. |
| 399 | | Arg. + 30 : 2513 Böotis | 14 17 23 | +29 52·9 | 6½ | "Orange red" (Espin). |
| *400 | 327 | 4775 B.A.C. Böotis | 14 18 53 | + 8 35·2 | 7 | Deep orange. "Yellowish red" (Brodie). "? Col. var." |
| 401 | 328 | 26342 Lal. Böotis | 14 19 14 | +26 12·2 | 8 | Pale red. "Ruby red" (Brodie). "? Var." |
| 402 | | 106 Virginis | 14 22 53 | − 6 24·3 | 6 | "Red" (*Uran. Arg.*). |
| 403 | 329 | — Virginis | 14 23 55 | − 5 29·5 | 8 | Reddish. "Pale red" (Brodie). "In neb." (D'Arrest). |
| 404 | 330 | ρ Böotis | 14 27 5 | +30 51·2 | 3½ | Full orange. "Reddish" (Brodie). |
| 405 | 332 | 5 Ursæ Minoris | 14 27 43 | +76 11·2 | 4¼ | Deep yellow. |
| 406 | 334 | 4825 B.A.C. Böotis | 14 30 8 | +37 6·5 | 6½ | Orange tinge. "Yellowish red" (Brodie). |
| 407 | 335 | α Centauri | 14 32 7 | −60 22·5 | 1 | "Red." "Rich yellow" (Tupman). |
| 408 | | — Libræ | 14 34 31 | −14 49·6 | 8 | Red. |
| 409 | | Arg. + 33 : 2482 Böotis | 14 34 37 | +33 0·5 | 8¼ | "Very red" (Espin). |
| 410 | | Arg. + 32 : 2504 Böotis | 14 36 33 | +32 1·5 | 8 | "Red" (Espin). |
| 411 | 337 | 34 Böotis | 14 38 35 | +26 59·8 | 5 | Reddish orange. |
| **412 | 339 | ε Böotis | 14 40 11 | +27 32·3 | 2½ | Golden yellow. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 413 | 340 | σ Libræ | 14 43 50 | −27 30·0 | 5 | Red. |
| **414 | 341 | β Ursæ Minoris | 14 51 2 | +74 36·3 | 2 | Deep golden yellow. "? Var." |
| 415 | | — Libræ | 14 51 42 | −11 59·4 | $7\frac{1}{3}$ | Red. |
| *416 | 342 | 4949 B.A.C. Ursæ Minoris | 14 55 50 | +66 22·2 | $4\frac{3}{4}$ | Orange. |
| *417 | 343 | 20 Libræ | 14 57 38 | −24 50·9 | $3\frac{1}{3}$ | Orange red. "Reddish" (Bellamy). "Red" (Robinson). "Not red" (*Washburn Obs.*). |
| 418 | 344 | ν Libræ | 15 0 29 | −15 49·7 | $5\frac{1}{3}$ | Reddish orange. |
| 419 | | 4984 B.A.C. Libræ | 15 3 26 | −23 33·9 | $7\frac{1}{3}$ | Good red. |
| 420 | 345 | 4976 B.A.C. Triang. Aust. | 15 3 46 | −69 39·8 | 6 | "Almost scarlet" (J. Herschel). "Red" (Stone). |
| 421 | 346 | δ Lupi | 15 11 8 | −29 44·6 | 5 | Red. |
| 422 | 347 | — Apodis | 15 14 3 | −75 32·0 | 7 | "Very high red" (J. Herschel). |
| 423 | | φ¹ Lupi | 15 14 49 | −35 51·7 | $3\frac{1}{3}$ | "Very red" (Gould). "Reddish yellow" (Williams). |
| 424 | | 6 Serpentis | 15 15 24 | + 1 7·0 | $5\frac{1}{2}$ | "Red" (*Uran. Arg.*). |
| 425 | | — Libræ | 15 16 10 | −28 47·2 | $8\frac{1}{2}$ | Perhaps reddish. |
| 426 | 351 | 11 Ursæ Minoris | 15 17 12 | +72 13·4 | 5 | Reddish. |
| 427 | 352 | ι Draconis | 15 22 29 | +59 21·1 | $3\frac{1}{3}$ | Yellow. |
| 428 | | ε Trianguli Australis | 15 26 39 | −65 56·7 | $4\frac{1}{2}$ | "Orange" (Tupman). |
| 429 | | 11 Serpentis | 15 27 18 | 0 48·8 | 6 | "Red" (*Uran. Arg.*). |
| 430 | 355 | 39 Libræ | 15 30 21 | −27 46·2 | 4 | Decided red. "Not red" (*Washburn Obs.*). |
| 431 | 356 | τ¹ Serpentis | 15 31 22 | +15 28·0 | $6\frac{1}{2}$ | Reddish. "Yellowish red" (Brodie). "? Var." |
| 432 | | 68 Espin Coronæ Borealis | 15 33 31 | +24 52·8 | 7 | Red. "Orange ruby" (Webb). |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 433 | 357 | θ Ursæ Minoris | 15 34 41 | +77 42·9 | $5\frac{1}{4}$ | Reddish. |
| 434 | | κ Libræ | 15 35 36 | −19 19·3 | 5 | Reddish orange. |
| 435 | 358 | κ Serpentis | 15 43 47 | +18 28·9 | 4 | Orange. |
| 436 | | ω Serpentis | 15 44 44 | + 2 32·0 | 5 | "Red" (*Uran. Arg.*). |
| 437 | 361 | — Coronæ Borealis | 15 45 36 | +39 54·4 | $8\frac{1}{2}$ | Good red. "Fine ruby" (J. Herschel). Var. |
| *438 | 363 | ρ Serpentis | 15 46 25 | +21 18·6 | $4\frac{3}{4}$ | Pale orange. |
| 439 | 365 | θ Libræ | 15 47 33 | −16 20·8 | $4\frac{1}{4}$ | Pale orange. |
| 440 | | 28997 Lal. Libræ | 15 50 57 | −15 43·0 | $6\frac{3}{4}$ | Red. "Reddish" (Robinson). |
| 441 | 367 | Arg. +47 : 2291 Coronæ Bor. | 15 59 25 | +47 32·3 | 7 | Red. |
| 442 | | 6661 Lac. Normæ | 15 59 42 | −52 46·9 | $6\frac{3}{4}$ | "Red" (Stone). |
| 443 | | 5347 B.A.C. Scorpii | 16 1 25 | −26 1·9 | $5\frac{3}{4}$ | Good red. |
| 444 | 369 | W.B. XV. 1569 Herculis | 16 2 37 | +22 7·0 | $6\frac{1}{2}$ | Reddish. "Straw colour" (*Washburn Obs.*). "Pale yellowish red" (Brodie). |
| 445 | | — Scorpii | 16 3 3 | −26 9·6 | $7\frac{1}{2}$ | Red. ? R.A. |
| 446 | 370 | 47 Serpentis | 16 3 10 | + 8 50·2 | $5\frac{3}{4}$ | Decidedly reddish. |
| 447 | 371 | Arg. +9 : 3151 Serpentis | 16 3 19 | + 8 55·2 | $7\frac{1}{2}$ | Orange. |
| 448 | 372 | 29441 Lal. Serpentis | 16 4 5 | + 1 6·8 | 7 | Reddish. "Yellowish red" (Brodie). "Lemon yellow" (*Washburn Obs.*). "? Var." |
| E **449 | 373 | δ Ophiuchi | 16 8 35 | − 3 24·6 | $2\frac{3}{4}$ | Reddish orange. "Orange red" (Robinson). |
| E 450 | 374 | — Normæ | 16 10 6 | −45 32·0 | $8\frac{1}{2}$ | "Ruby red" (J. Herschel). |
| *451 | 375 | ε Ophiuchi | 16 12 29 | − 4 25·3 | $3\frac{1}{2}$ | Golden yellow. "? Var." |
| **452 | 376 | ν¹ Coronæ Borealis | 16 18 13 | +34 4·5 | 5 | Orange. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| **453 | 377 | $\nu^2$ Coronæ Borealis | 16 18 21 | +33 57·4 | 5 | Orange. |
| 454 | 379 | — Ophiuchi | 16 20 37 | −12 10·1 | 8 | No star of this mag. here. "Red or crimson" (Brodie). "Dull brick red" (J. Herschel). "? Var." (Birm.). Dunèr's Var. |
| **455 | 381 | α Scorpii | 16 22 39 | −26 11·2 | 1 | Fiery red. |
| 456 | 383 | β Herculis | 16 25 30 | +21 43·8 | 2¾ | Golden. |
| 457 | | 69 Espin Herculis | 16 27 0 | +35 27·6 | 6½ | Reddish orange. = 30129 Lal. |
| 458 | 384 | 111 P. XVI. Scorpii | 16 29 8 | −35 1·7 | 5½ | "Red." |
| 459 | | — Ophiuchi | 16 33 6 | −12 6·3 | 8 | Reddish. |
| 460 | 385 | — Scorpii | 16 33 34 | −32 9·7 | 8 | "Deep red, like a drop of blood" (J. Herschel). |
| 461 | | α Trianguli Australis | 16 37 1 | −68 49·5 | 2¼ | "Orange; yellow" (Tupman). |
| 462 | 386 | Arg. + 36 : 2772 Herculis | 16 39 11 | +36 43·2 | 8 | Reddish; in the field with cl. 13 M. |
| 463 | | η Aræ | 16 40 17 | −58 50·6 | 4 | "Orange" (Tupman). |
| 464 | | ε Scorpii | 16 43 3 | −34 5·5 | 2¼ | "Orange; yellow" (Tupman). |
| 465 | 388 | 30593 Lal. Ophiuchi | 16 43 42 | + 0 7·0 | 8 | Very slight tinge. ? Mag. |
| 466 | 389 | W.B. XVI. 1347 Herculis | 16 43 48 | +42 26·1 | 7 | Pale orange. |
| 467 | | $\zeta^2$ Scorpii | 16 46 50 | −42 10·3 | 3 | "Deep orange yellow" (Williams). |
| 468 | | ζ Aræ | 16 49 31 | −55 48·9 | 4 | "Bright orange" (Tupman). |
| 469 | 394 | 30790 Lal. Ophiuchi | 16 50 31 | + 1 35·9 | 8 | Pinkish. "With red blush" (Brodie). |
| 470 | 395 | κ Ophiuchi | 16 52 27 | + 9 32·8 | 3½ | Golden. "Perhaps var." |
| 471 | 399 | 30 Ophiuchi | 16 55 16 | − 4 3·5 | 5 | Reddish orange. "Probably var." |

| Number. G.F.C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 472 | 400 | 61 Herculis | 16 59 36 | +34 33·6 | 7 | Pale orange. |
| 473 | | 70 Espin Herculis | 16 59 6 | +35 33·8 | 6½ | Reddish orange. |
| **474 | 402 | $\alpha^1$ Herculis | 17 9 38 | +14 31·0 | 3¼ | Deep orange. "Reddish" (Robinson). "Var." |
| 475 | | — Ophiuchi | 17 9 59 | −15 5·3 | 7½ | Fiery red. |
| 476 | 404 | π Herculis | 17 11 13 | +36 56·1 | 3½ | Fiery orange. "? Var." |
| 477 | 405 | υ Herculis | 17 13 15 | +33 13·0 | 5 | Yellow. |
| 478 | 407 | — Ophiuchi | 17 14 14 | + 2 16·2 | 7 | Red. |
| 479 | | 73 Espin Herculis | 17 15 50 | +17 9·9 | 7½ | Red. ? Decl. |
| 480 | | β Aræ | 17 16 9 | −55 25·6 | 3 | "Deep bright orange" (Tupman). |
| 481 | 408 | 43 Ophiuchi | 17 16 26 | −28 2·3 | 5½ | Reddish. |
| 482 | | δ Aræ | 17 21 10 | −60 35·4 | 3 | "Pale orange" (Tupman). |
| 483 | 409 | — Scorpii | 17 22 49 | −35 33·1 | 9 | "Very deep red" (J. Herschel). |
| **484 | 410 | — Ophiuchi | 17 23 14 | −19 23·1 | 8 | Very decided red. "Ruby star" (J. Herschel). "Deep red, nearly crimson" (Brodie). |
| 485 | 411 | λ Herculis | 17 25 17 | +26 11·6 | 4¼ | Pale orange. |
| 486 | 412 | β Draconis | 17 27 57 | +52 22·9 | 3 | Golden. |
| 487 | 414 | — Scorpii | 17 32 38 | −41 33·5 | 8 | "Ruby red" (J. Herschel). |
| 488 | 415 | — Aræ | 17 33 51 | −57 40·2 | 8 | "Scarlet or high orange" (J. Herschel). |
| 489 | 416 | 5986 B.A.C. Herculis | 17 35 48 | +31 15·7 | 6½ | Yellowish. |
| 490 | 417 | β Ophiuchi | 17 38 2 | + 4 36·8 | 3 | Pale orange. |
| 491 | 418 | — Serpentis | 17 38 28 | −18 36·4 | 8½ | Very little colour. "Probably var. in colour and mag." |

| Number. G. C. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 492 | | -- Ophiuchi | 17 41 57 | − 3 36·3 | 8 | Reddish. |
| 493 | | 76 Espin Herculis | 17 42 58 | +36 7·4 | 6½ | Reddish orange. |
| 494 | | 77 Espin Herculis | 17 44 4 | +36 35·6 | 6½ | Reddish orange. |
| 495 | | 78 Espin Ophiuchi | 17 45 36 | +11 58·8 | 6¾ | Orange. Assumed to be 877 Weisse. |
| 496 | | 79 Espin Ophiuchi | 17 46 27 | + 1 8·1 | 7 | Red. ? 886 Weisse. |
| 497 | | 80 Espin Ophiuchi | 17 46 57 | + 1 20·4 | 6½ | Fiery red. |
| 498 | 421 | ξ Draconis | 17 51 35 | +56 53·3 | 4 | Pale orange. |
| 499 | 422 | — Ophiuchi | 17 52 32 | + 2 44·0 | 7 | Reddish. "? Var." |
| **500 | 423 | γ Draconis | 17 54 3 | +51 30·1 | 2½ | Fiery orange. |
| 501 | 425 | γ Sagittarii | 17 58 44 | −30 25·4 | 3 | Reddish orange. "? Var." |
| 502 | 427 | — Sagittarii | 18 3 24 | −15 18·1 | 8 | Slightly coloured. "Pale red" (Brodie). "? Var." |
| 503 | 430 | A (104) Herculis | 18 7 47 | +31 22·7 | 5 | Orange. |
| 504 | | 7634 Lac. Sagittarii | 18 8 3 | −29 51·3 | 7½ | "Reddish" (*Washburn Obs.*) |
| 505 | 431 | Arg. +22 : 3303 Herculis | 18 8 15 | +22 48·1 | 7½ | Pale orange. |
| 506 | | — Sagittarii | 18 8 36 | −18 56·9 | 8 | Fiery red. ? Mag. |
| 507 | 432 | η Sagittarii | 18 10 11 | −36 47·8 | 3 | "Deep golden yellow" (Schmidt). |
| 508 | | — Sagittarii | 18 11 55 | −18 17·9 | 8 | Reddish. |
| 509 | | 81 Espin Herculis | 18 12 55 | +17 55·5 | 7 | Deep red. |
| 510 | 433 | Arg. +23 : 3299 Herculis | 18 13 32 | +23 14·3 | 7 | Orange. |
| 511 | 434 | δ Sagittarii | 18 13 57 | −29 52·5 | 2¾ | Orange red. |
| 512 | 435 | 33933 Lal. Serpentis | 18 13 49 | + 0 47·9 | 8 | Reddish. "Very pale red" (Brodie). |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| *513 | 437 | 33896 Lal. Herculis | 18 16 57 | +25 0·2 | 7½ | Rich orange. "No red star here" (*Washburn Obs.*). ? R.A. too great by 1ᵐ 28ˢ; Decl. too great by 35′. |
| 514 | 438 | — Serpentis | 18 18 17 | − 1 38·3 | 7 | Yellowish. "Double: A, 6, yellow; B, 7, blue" (Secchi). |
| 515 | 439 | 21 Sagittarii | 18 18 46 | −20 36·1 | 5 | Red. |
| *516 | 440 | 109 Herculis | 18 18 59 | +21 43·5 | 4 | Golden yellow. |
| 517 | 441 | λ Sagittarii | 18 21 11 | −25 28·9 | 3 | Reddish orange. |
| 518 | | 60 Serpentis | 18 23 57 | − 2 3·4 | 5½ | "Red" (*Uran. Arg.*) |
| **519 | 446 | 6306 B.A.C. Sagittarii | 18 26 27 | −14 56·4 | 5¾ | Fiery red. "Golden yellow" (Brodie). "Reddish" (Bellamy). |
| 520 | 447 | 34307 Lal. Aquilæ | 18 27 16 | − 5 14·5 | 7½ | Tinge of orange. "? Colour var." "Very pale red" (Brodie). |
| **521 | 448 | Arg. +36 : 3168 Lyræ | 18 28 30 | +36 54·5 | 8 | Decided crimson. "? Var." |
| *522 | 449 | 1 Aquilæ | 18 29 13 | − 8 18·9 | 4 | Good orange. |
| 523 | 451 | 123 P. XVIII. Clyp. Sob. | 18 30 12 | − 6 49·9 | 7 | Reddish. |
| 524 | | 82 Espin Lyræ | 18 30 23 | +38 21·1 | 7 | Red. |
| 525 | 452 | 6341 B.A.C. Herculis | 18 30 57 | +23 30·0 | 5¾ | Orange. |
| 526 | 453 | 34507 Lal. Aquilæ | 18 32 40 | −13 52·6 | 8 | Scarcely tinged. Colour changed since 1873. |
| 527 | 454 | — Serpentis | 18 32 42 | +11 21·3 | 8⅓ | Reddish. |
| 528 | | 83 Espin Lyræ | 18 33 46 | +37 41·0 | 7 | Red. "Pale ruby" (Webb). |
| 529 | 457 | 34746 Lal. Aquilæ | 18 38 22 | − 6 38·9 | 7 | Reddish. |
| 530 | 458 | Arg. +36 : 3243 Lyræ | 18 39 1 | +36 51·2 | 8 | Fiery red. ? Var. "No really red star here" (*Washburn Obs.*). |
| 531 | 459 | Arg. +39 : 3505 Lyræ | 18 39 37 | +39 11·5 | 7 | Slightly red. ? Colour var. Has a small *comes.* |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 532 | 461 | Arg. + 33 : 3192 Lyræ | 18 40 50 | + 33 4·5 | 8 | Reddish. |
| 533 | 463 | Arg. + 18 : 3817 Herculis | 18 41 52 | + 18 35·1 | 7 | Pale orange. |
| **534 | 464 | — Clypei Sobieskii | 18 43 50 | − 8 1·9 | 8 | Rich fiery red. "? Var." "Orange" (Brodie). |
| *535 | 466 | $\nu^1$ Sagittarii | 18 47 32 | − 22 52·8 | 5 | Red. |
| 536 | 468 | $\nu^2$ Sagittarii | 18 48 27 | − 22 48·5 | 5¼ | Pale orange. |
| 537 | | 62 Serpentis | 18 50 6 | − 6 28·8 | 6 | "Red" (*Uran. Arg.*). |
| 538 | 470 | $\delta^2$ Lyræ | 18 50 39 | + 36 45·5 | 4½ | Fiery orange. |
| 539 | | 9 Aquilæ | 18 51 10 | − 5 59·3 | 5 | "Red" (*Uran. Arg.*). |
| *540 | 471 | $\xi^2$ Sagittarii | 18 51 9 | − 21 15·1 | 3½ | Orange. |
| 541 | 472 | W. B. XVIII. 1528 Herculis | 18 51 15 | + 17 58·3 | 5¾ | Pale orange. |
| 542 | 473 | — Aquilæ | 18 51 57 | + 0 18·5 | 9 | Red. "Orange red" (Brodie). |
| *543 | 475 | — Aquilæ | 18 52 31 | + 14 12·6 | 9 | Deep red. |
| 544 | | 87 Espin Lyræ | 18 53 16 | + 36 19·3 | 7 | Orange. |
| 545 | 476 | Arg. + 38 : 3362 Lyræ | 18 53 23 | + 38 39·2 | 7½ | Pale orange. |
| 546 | 477 | Arg. + 22 : 3549 Vulpeculæ | 18 55 19 | + 22 39·7 | 6½ | Golden. |
| **547 | 478 | 12 Aquilæ | 18 55 47 | − 5 53·5 | 4 | Orange. "? Var." |
| 548 | 479 | $\lambda$ Lyræ | 18 55 51 | + 31 59·4 | 5¼ | Orange. "? Var." |
| 549 | 480 | 35562 Lal. Aquilæ | 18 57 4 | + 8 12·8 | 6½ | Pale orange. |
| 550 | 481 | $o$ Sagittarii | 18 58 5 | − 21 54·1 | 4 | Full yellow. |
| 551 | 482 | 35624 Lal. Aquilæ | 18 58 15 | + 8 8·1 | 8 | Decided yellow. |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| **552 | 483 | 35611 Lal. Aquilæ | 18 58 32 | − 5 50·9 | 7½ | Very fine fiery red. "? Var." "Decided red" (Brodie). "Deep red" (Wickham). |
| 553 | 485 | τ Sagittarii | 19 0 5 | −27 49·6 | 3½ | Reddish orange. |
| 554 | 487 | 35928 Lal. Vulpeculæ | 19 4 2 | +24 0·3 | 7 | Reddish. |
| 555 | | 89 Espin Lyræ | 19 4 28 | +38 58·7 | 7 | Orange. = 78 Weisse. |
| 556 | 490 | Arg. +18 : 4011 Sagittæ | 19 10 42 | +18 19·8 | 7 | Orange. |
| 557 | 491 | δ Draconis | 19 12 32 | +67 28·0 | 3¼ | Fine golden yellow. |
| 558 | | 91 Espin Lyræ | 19 13 22 | +38 47·6 | 6¾ | Red. |
| 559 | 492 | — Lyræ | 19 14 49 | +27 3·2 | 9 | Red. "? Var." |
| 560 | 493 | Arg. +22 : 3660 Vulpeculæ | 19 14 51 | +22 21·9 | 8 | Reddish. |
| 561 | | 93 Espin Sagittæ | 19 16 43 | +17 27·5 | 9½ | Good red. "? Var." (Espin). |
| 562 | | 4 Vulpeculæ | 19 20 38 | +19 35·0 | 5¼ | Orange; fine field. |
| *563 | 494 | 3 Cygni | 19 20 54 | +24 42·9 | 6 | Orange. |
| **564 | 495 | — Vulpeculæ | 19 21 30 | +19 34·8 | 6 | Yellowish. |
| 565 | 496 | 128 P. XIX. Vulpeculæ | 19 21 40 | +19 40·3 | 6¼ | Reddish orange. |
| *566 | | 94 Espin Cygni | 19 21 44 | +50 1·0 | 7 | Fiery red. |
| 567 | 498 | Arg. +1 : 4004 Aquilæ | 19 22 17 | + 1 57·2 | 8 | Reddish. "? var." |
| 568 | 499 | Arg. +2 : 3904 Aquilæ | 19 24 39 | + 2 40·6 | 6½ | Reddish orange. |
| *569 | 500 | 36 (*e*) Aquilæ | 19 24 54 | − 3 1·1 | 5¼ | Strong reddish orange. "Light orange" (Brodie). |
| 570 | | 179 Espin Cygni | 19 25 21 | +45 48·9 | 8 | "Very red; ? var." (Espin). |
| 571 | 501 | Arg. +1 : 4021 Aquilæ | 19 25 30 | + 1 47·4 | 8 | Golden. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| **572 | 502 | 6702 B.A.C. Draconis | 19 25 30 | +76 21·1 | 6½ | Strong fiery red. "? Var." "Reddish orange" (Brodie). |
| **573 | 503 | β Cygni | 19 26 17 | +27 43·7 | 3 | Rich yellow, with a 7th mag. *comes* blue. "? Var." |
| 574 | 504 | Arg. + 4 : 4152 Aquilæ | 19 27 43 | + 4 47·6 | 7 | Reddish orange. |
| 575 | 505 | 36981 Lal. Sagittarii | 19 28 0 | −16 37·8 | 7½ | Orange. "Good ruby" (J. Herschel). "Fiery red" (Gore, 1876). "Red; deeper at times" (Bellamy). ? Var. in colour; no trace of ruby (G.F.C.). |
| 576 | 506 | Arg. + 5 : 4190 Aquilæ | 19 28 23 | + 5 13·5 | 7 | Golden. |
| 577 | | 97 Espin Vulpeculæ | 19 31 12 | +23 36·3 | 8 | Reddish. |
| 578 | | 98 Espin Vulpeculæ | 19 35 13 | +17 38·4 | 8 | Rich orange. "Pale ruby" (Webb). |
| 579 | 509 | Arg. + 32 : 3522 Cygni | 19 36 55 | +32 21·9 | 8 | Red. |
| 580 | 510 | 37504 Lal. Aquilæ | 19 38 44 | + 4 42·0 | 8 | Reddish. "Reddish tinge" (Brodie). "? Var." |
| 581 | 511 | Arg. + 12 : 4060 Aquilæ | 19 39 29 | +12 58·0 | 7 | Reddish. |
| *582 | | 101 Espin Cygni | 19 40 16 | +40 26·6 | 6 | Fiery red. |
| 583 | 512 | γ Aquilæ | 19 41 2 | +10 20·7 | 2¾ | Brilliant orange. "Reddish yellow" (Robinson). |
| 584 | | 104 Espin Aquilæ | 19 42 18 | + 9 45·9 | 8 | Red, with blue companion; dist. ± 50″. |
| 585 | 515 | Arg. + 22 : 3812 Vulpeculæ | 19 43 28 | +22 29·9 | 8 | Reddish. |
| 586 | 518 | χ Cygni | 19 46 20 | +32 38·3 | Var. 4–0 | Fiery red, when approaching max. |
| 587 | 519 | 19 Cygni | 19 46 39 | +38 26·1 | 5½ | Full orange. |
| 588 | 521 | Arg. + 43 : 3425 Cygni | 19 53 37 | +43 57·5 | 8 | Fiery red. |
| 589 | | 109 Espin Sagittæ | 19 55 8 | +17 18·3 | 7½ | Fine orange; there is a red 9th mag. S. |
| 590 | 522 | o Sagittarii | 19 55 53 | −28 1·0 | 4¾ | |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 591 | | 181 Espin Cygni | 19 56 30 | +30 31·2 | 9¼ | " Very red " (Espin). |
| 592 | 525 | Arg. + 36 : 3820 Cygni | 19 57 13 | +36 47·6 | 7 | Pale orange. |
| 593 | | 38428 Lal. Cygni | 19 59 41 | +38 0·6 | | Reddish. |
| 594 | 526 | Ö-Arg. (2) 20234 Sagittarii | 20 0 12 | −27 32·5 | 7 | " Ruby " (J. Herschel). " Deep orange red " (Brodie). |
| 595 | 528 | −- Pavonis | 20 1 38 | −60 15·2 | 8½ | " Very red " (J. Herschel). |
| 596 | 530 | Arg. + 16 : 4153 Sagittæ | 20 3 8 | +16 21·4 | 6½ | Orange. |
| 597 | 537 | 19 Vulpeculæ | 20 7 12 | +26 29·0 | 5¾ | Reddish orange. |
| *598 | 538 | 66 Aquilæ | 20 7 33 | − 1 20·3 | 5¾ | Orange. |
| 599 | 541 | Arg. + 38 : 3957 Cygni | 20 9 24 | +38 23·7 | 8 | Decided red. |
| *600 | 543 | $o^1$ Cygni | 20 10 10 | +46 24·5 | 3¾ | Fine golden yellow; *comes* blue. |
| 601 | 544 | Arg. + 36 : 3956 Cygni | 20 10 25 | +36 19·6 | 8 | Reddish. |
| *602 | 545 | Ö-Arg. (2) 20363 Capricorni. | 20 10 40 | −21 39·3 | 7½ | Decided red. " Perhaps the finest of my ruby stars " (J. Herschel). " Deep ruby; fine colour " (Brodie). " Bright ruby " (Bellamy). |
| 603 | 546 | 23 Vulpeculæ | 20 11 13 | +27 28·6 | 4¾ | Full orange. |
| **604 | 547 | $\alpha^1$ Capricorni | 20 11 33 | −12 50·9 | 4½ | Golden yellow. |
| **605 | 548 | $\alpha^2$ Capricorni | 20 11 57 | −12 53·1 | 3¾ | Golden yellow. |
| 606 | 549 | $o^2$ (32) Cygni | 20 12 5 | +47 22·6 | 4½ | Pale orange. |
| 607 | 551 | 6986 B.A.C. Cygni | 20 12 59 | +40 1·3 | 5½ | Reddish orange. |
| *608 | 550 | $\sigma$ Capricorni | 20 13 3 | −19 27·7 | 5½ | Double. A golden; B colourless or ruddy. Dist. 50″. |
| 609 | 552 | 38988 Lal. Aquilæ | 20 13 21 | + 0 15·2 | 8¾ | Red. |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 610 | 553 | U Cygni | 20 16 12 | +47 32·9 | 7–11 | Red. "Remarkable ruby." "Var." |
| 611 | | 115 Espin Cygni | 20 17 37 | +53 14·2 | 7 | Reddish. |
| 612 | 555 | 7027 B.A.C. Cygni | 20 18 50 | +40 40·4 | 6 | Reddish yellow. |
| 613 | 556 | — Aquilæ | 20 19 10 | + 0 11·8 | 10 | Reddish. ? Var. Mag. 8½, Aug. 9, 1885. |
| 614 | 557 | 39 Cygni | 20 19 28 | +31 50·1 | 4½ | Reddish orange. |
| 615 | 558 | 39304 Lal. Delphini | 20 20 27 | + 9 42·0 | 7 | Pale orange. "Probably var." |
| 616 | | 116 Espin Cygni | 20 20 46 | +39 47·5 | 7½ | Reddish. "Orange ruby" (Webb). |
| 617 | 559 | — Capricorni | 20 21 12 | −28 37·4 | 8 | Decided red. "Fine ruby" (J. Herschel). |
| 618 | 560 | $\omega^1$ Cygni | 20 23 40 | +49 1·1 | 5 | Golden yellow. |
| *619 | | 117 Espin Delphini | 20 24 2 | +15 53·8 | 8½ | Good red. There is a blue 8th mag. S. |
| 620 | | 118 Espin Cygni | 20 24 47 | +39 36·7 | 9 | Fiery red. "Colour very fine" (Espin). |
| *621 | 562 | $\omega^2$ Cygni | 20 27 55 | +48 50·9 | 5½ | Deep golden yellow. |
| 622 | 563 | 47 Cygni | 20 29 37 | +34 52·4 | 4¾ | Orange. |
| *623 | 564 | 70 Aquilæ | 20 31 0 | − 2 55·9 | 5¼ | Full orange. |
| 624 | 565 | — Aquilæ | 20 32 41 | + 0 37·6 | 8½ | Reddish. |
| *625 | 566 | Arg. + 17 : 4370 Delphini | 20 32 54 | +17 52·7 | 7 | Full orange. |
| 626 | 569 | Arg. + 17 : 4401 Delphini | 20 40 25 | +17 41·5 | 7 | Reddish. "Probably var." |
| **627 | 570 | ε Cygni | 20 41 45 | +33 33·4 | 2¾ | Fine golden yellow. |
| 628 | | 119 Espin Cygni | 20 43 4 | +45 38·7 | 8½ | Pale ruby. |
| 629 | | 120 Espin Cygni | 20 45 4 | +45 26·7 | 8½ | Fiery red. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 630 | | 121 Espin Cygni | 20 46 8 | +50 22·0 | 7½ | Red. |
| 631 | | 122 Espin Cygni | 20 47 20 | +49 42·6 | 7 | Deep orange. |
| 632 | 572 | Arg. + 32 : 3980 Cygni | 20 49 26 | +33 0·0 | 5¾ | Orange. |
| 633 | 573 | 1294 Bess. Delphini | 20 52 4 | +15 49·8 | 8 | Yellowish. "Pale orange tinge" (Brodie). "Probably var. both in mag. and colour." |
| 634 | | 123 Espin Cygni | 20 54 10 | +45 48·9 | 8 | Fiery red. |
| 635 | | ζ (3) Equulei | 20 59 6 | + 5 3·9 | 5¾ | Fiery red. "Red" (*Uran. Arg.*) |
| 636 | 575 | A Capricorni | 21 0 42 | −25 26·7 | 4½ | Deep orange. |
| 637 | 576 | ξ Cygni | 21 0 56 | +43 29·3 | 3¾ | Deep golden yellow. |
| 638 | | — Capricorni | 21 1 6 | −16 51·7 | 8½ | Reddish. |
| 639 | | 124 Espin Cygni | 21 6 40 | +47 12·4 | 7½ | Orange; a blue 7¼ mag. to the N. |
| *640 | 579 | 61 P. XXI. Cephei | 21 10 2 | +59 39·7 | 7½ | Remarkable fiery red. "Orange red" (Brodie). "? Var." |
| 641 | 580 | 8745 Lac. Indi | 21 14 19 | −70 11·7 | 6 | "Red, inclining to orange" (J. Herschel). |
| 642 | | 125 Espin Cygni | 21 14 58 | +49 36·1 | 7 | Fiery red. |
| *643 | 582 | — Cygni | 21 17 53 | +41 55·7 | 9 | Deep red. |
| 644 | | 33 Capricorni | 21 17 55 | −21 19·1 | 5½ | "Red" (Gore). |
| 645 | | 184 Espin Cygni | 21 19 5 | +40 28·1 | 7½ | "Red" (Espin). |
| *646 | 583 | 2 Pegasi | 21 24 58 | +23 9·4 | 4¾ | Bright orange. |
| 647 | 585 | Arg. + 45 : 3584 Cygni | 21 29 9 | +45 21·9 | 7 | Reddish orange. |

| Number. G. F. C. | Number. Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 648 | 586 | — Cephei | 21 30 37 | +58 13·4 | 6 | Intense orange. |
| 649 | 587 | Arg. +44 : 3877 Cygni | 21 31 53 | +44 53·1 | 7 | Reddish orange. |
| 650 | 589 | 889 Bess. Cygni | 21 37 23 | +35 0·4 | 7 | Unmistakable fiery red. |
| 651 | 590 | — Cygni | 21 37 24 | +42 20·4 | 7 | Strong reddish tinge. "Schmidt's *Nova* of 1876." |
| 652 | | 129 Espin Cygni | 21 37 53 | +48 41·5 | 8¾ | Orange. |
| **653 | 591 | ε Pegasi | 21 38 47 | + 9 22·2 | 2½ | Full orange. "Probably var." |
| 654 | | 130 Espin Cephei | 21 38 41 | +70 17·1 | 8 | Orange. |
| **655 | 592 | 923 Bess. Cygni | 21 38 43 | +37 30·7 | 8 | Deep fiery red or pale crimson. "Good red" (Brodie). |
| **656 | 594 | $\mu$ Cephei | 21 40 8 | +58 16·5 | 4-6 | Intense reddish orange. "Light orange" (Brodie). |
| 657 | | 47 Capricorni | 21 40 24 | − 9 47·0 | 6½ | "Orange red" (Espin). |
| **658 | 596 | 42431 Lal. Aquarii | 21 40 50 | − 2 43·4 | 6¼ | Decided red. "? Var." "Red" (Robinson). |
| 659 | | 131 Espin Cephei | 21 42 45 | +57 33·4 | 8 | Reddish orange. |
| 660 | 598 | — Cygni | 21 51 6 | +49 59·3 | 9 | Pale red. |
| *661 | 599 | 7658 B.A.C. Cephei | 21 53 33 | +63 5·7 | 5¼ | Fiery orange. |
| *662 | | 133 Espin Cephei | 21 54 22 | +65 37·6 | 6½ | Fiery red. Blue star 6½ mag. near. |
| *663 | 600 | — Pegasi | 21 58 59 | +27 49·1 | 7½ | Fiery red. "Orange tinge" (Brodie). "? Var." |
| 664 | 601 | 18 Cephei | 22 0 39 | +62 33·8 | 5½ | Reddish orange. |
| 665 | 602 | 20 Cephei | 22 1 40 | +62 14·9 | 5½ | Orange. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 666 | | 134 Espin Lacertæ | 22 6 30 | +39 9·9 | 7¼ | Reddish. |
| 667 | 604 | ζ Cephei | 22 7 3 | +57 39·5 | 3½ | Pale orange. |
| 668 | 606 | 7766 B.A.C. Cephei | 22 8 56 | +62 43·5 | 6 | Reddish orange. |
| 669 | 607 | 7765 B.A.C. Lacertæ | 22 9 9 | +39 10·0 | 4½ | Pale orange. |
| 670 | 608 | 1 Lacertæ | 22 11 10 | +37 12·1 | 4¼ | Bright yellow. |
| 671 | 609 | 43501 Lal. Pegasi | 22 11 56 | + 4 35·8 | 7¾ | Dull pale red. "Tinge of red" (Brodie). |
| 672 | 610 | 7813 B.A.C. Cephei | 22 18 59 | +55 24·4 | 7 | Good red. "Orange" (Brodie). |
| 673 | 611 | β Lacertæ | 22 19 14 | +51 40·8 | 4½ | Golden. |
| 674 | | 35 Pegasi | 22 22 17 | + 4 8·7 | 5 | Deep orange. "Red" (*Uran. Arg*). |
| 675 | | 36 Pegasi | 22 23 39 | + 8 34·1 | 6 | Reddish orange. "Red" (*Uran. Arg.*). |
| 676 | 612 | 5 Lacertæ | 22 24 57 | +47 8·7 | 4½ | Reddish orange. |
| 677 | 613 | δ Cephei | 22 25 5 | +57 51·1 | 3½–4½ | Orange; with blue companion in good contrast. "Var." |
| 678 | | β Piscis Australis | 22 25 15 | −32 54·6 | 5 | "Wide double. A white; B 8, reddish lilac" (Gore). |
| 679 | | 135 Espin Cephei | 22 26 11 | +56 25·8 | 8 | Fiery red. |
| 680 | 615 | Arg. +56 : 2821 Cephei | 22 34 18 | +56 13·6 | 5½ | Reddish. |
| 681 | | 136 Espin Cephei | 22 30 23 | +57 36·1 | 7½ | Fiery red. |
| 682 | | 137 Espin Cephei | 22 32 35 | +57 51·4 | 7¼ | Red. "Var. 7–8" (Espin). |
| 683 | 616 | 11 Lacertæ | 22 35 40 | +43 42·1 | 4¾ | Reddish. |
| 684 | 617 | β Gruis | 22 36 6 | −47 27·7 | 3 | "Reddish." "Orange" (Williams). |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour ; Remarks. |
|---|---|---|---|---|---|---|
| 685 | 618 | $g^2$ Aquarii | 22 41 39 | −20 31·0 | 5½ | Golden yellow. |
| *686 | 620 | $\tau^2$ Aquarii | 22 44 47 | −14 10·4 | 4 | Orange. "? Var." |
| 687 | 621 | λ Aquarii | 22 46 52 | − 8 9·9 | 3¾ | Full golden yellow. "Reddish" (Robinson). |
| 688 | 622 | 15 Lacertæ | 22 47 5 | +42 43·7 | 5 | Reddish. |
| 689 | | 138 Espin Lacertæ | 22 52 25 | +42 25·1 | 7 | Orange. |
| 690 | 625 | 267 P. XXII. Aquarii | 22 53 7 | −25 45·0 | 6 | Reddish. "Pale red" (Brodie). |
| 691 | 626 | — Piscium | 22 55 39 | + 0 29·6 | 8½ | Slightly tinged. "Reddish tinge" (Brodie). |
| **692 | 627 | β Pegasi | 22 58 25 | +27 29·0 | 2½ | Rich golden. |
| **693 | 629 | 55 Pegasi | 23 1 27 | + 8 48·8 | 4½ | Deep yellow. |
| 694 | 630 | 57 Pegasi | 23 3 59 | + 8 4·8 | 5½ | Reddish orange. |
| 695 | | W.B. XXIII. 48 Piscium | 23 5 38 | + 4 24·2 | 8 | Orange. |
| 696 | 631 | Aquarii 286 | 23 8 2 | −13 59·8 | 7 | Reddish. "Double, A 7; B 10; dist. 1″·40." |
| 697 | 632 | φ Aquarii | 23 8 37 | − 6 38·3 | 4¼ | Deep orange. |
| 698 | 633 | $\psi^1$ Aquarii | 23 10 5 | − 9 41·1 | 4½ | Orange. |
| 699 | 634 | χ Aquarii | 23 11 9 | − 8 19·4 | 5¼ | Orange. |
| **700 | 635 | 8 Andromedæ | 23 12 38 | +48 24·9 | 5 | Fine golden yellow. "Orange red" (Brodie). |
| 701 | 636 | 94 Aquarii | 23 13 28 | −14 3·4 | 5¼ | Orange. |
| 702 | 637 | 262 Bess. Pegasi | 23 14 44 | +22 29·4 | 7 | Orange. "? Var." |
| 703 | 639 | 2557 Arg. Cassiopeiæ | 23 19 22 | +60 59·6 | 8¾ | Reddish. In cl. h 2238. |

| Number. G. F. C. | Birm. | Star. | R.A. 1890. h m s | Dec. 1890. ° ′ | Mag. | Colour; Remarks. |
|---|---|---|---|---|---|---|
| 704 | 642 | 46112 Lal. Pegasi | 23 27 0 | +23 14·3 | 7 | Pale orange. |
| 705 | 643 | 71 Pegasi | 23 27 59 | +21 54·9 | 5½ | Deep orange. |
| 706 | 644 | λ Andromedæ | 23 32 10 | +45 51·7 | 4 | Golden yellow. |
| 707 | 645 | 77 Pegasi | 23 37 46 | + 9 43·2 | 5½ | Deep orange. |
| 708 | 647 | 78 Pegasi | 23 38 27 | +28 45·1 | 5 | Pale orange. |
| **709 | 648 | 19 Piscium | 23 40 45 | + 2 52·5 | 5¼ | Decided red. "Probably var." |
| 710 | 651 | 4154 Groom. Cephei | 23 47 0 | +74 55·0 | 6¼ | Pale orange. |
| 711 | 652 | ρ Cassiopeiæ | 23 48 53 | +56 53·2 | 4½ | Yellow. |
| 712 | 653 | 235 P. XXIII. Pegasi | 23 51 5 | +22 2·1 | 6 | Reddish. "Slightly red" (*Uran. Oxon.*). |
| 713 | 654 | 9659 Lac. Sculptoris | 23 51 28 | −27 14·2 | 6½ | Reddish. |
| **714 | 655 | ψ Pegasi | 23 52 9 | +24 31·9 | 4⅓ | Reddish yellow. |
| **715 | 656 | R Cassiopeiæ | 23 52 49 | +50 46·4 | 5–12 | Very red. "Vivid red" (Brodie). "Var." |
| 716 | 657 | W.B. XXIII. 1090 Piscium | 23 54 56 | + 0 27·1 | 8¾ | Pale orange. |
| **717 | 658 | 6259 Rad. Cassiopeiæ | 23 55 39 | +59 44·5 | 8 | Fiery red. A 9th mag. blue star near. "Orange red" (Brodie). |
| *718 | | 30 Piscium | 23 56 19 | − 6 37·5 | 4½ | Fiery red. "Red" (*Uran. Arg.*). |
| 719 | | 33 Piscium | 23 59 42 | − 6 19·4 | 4¾ | Orange. "Red" (*Uran. Arg.*). |

*Northfield Observatory, Eastbourne, Sussex :*
*April*, 1887.

*Description of a New Measuring Rod.* By Edward Crossley.

Some ten years ago I had occasion to triangulate across a valley 3,000 feet wide on the south side of my observatory at Bermerside, Halifax. In order to accomplish this with sufficient accuracy it was necessary to measure a base line to 1 in 10,000. I soon discovered that no *simple* and *accurate* method had yet been devised for this purpose. The ordinary surveyor's chain or steel tape was quite inadequate for the purpose, especially as the ground was more or less uneven. The elaborate methods used in geodetic surveys were also out of the question on account of their great complexity. I therefore determined to construct a measuring rod on simple geometric principles, capable of doing accurate and rapid work over uneven ground, with or without the aid of an assistant.

The first rod I designed for this purpose was made for me by Messrs. T. Cooke and Sons of York. It was made of well-seasoned red deal, 1 inch thick, 6 feet in length, with a T section $2\frac{1}{2}$ inches wide and 4 inches deep in the centre. At each end, on the under flat surfaces, brass plates were attached with spherical cups in their centres, facing downwards. In the middle of the rod was placed a clinometer reading to $30''$ of arc. Three stout, firm tripods were used for carrying the rod. Each tripod terminated in a flat iron ring, faced in the lathe, $6\frac{1}{2}$ inches in outside diameter and 4 inches internal diameter. On these rings were placed brass pedestals with circular bases 6 inches diameter, surmounted by spheres or balls $\frac{7}{8}$ inch diameter, the top of the balls not being more than $2\frac{1}{2}$ inches above the surface of the rings. Each pedestal had a spindle going through the ring, with a brass tribrach "washer" and clamp, milled head screw nut on the under side of the iron ring, so that the pedestal could be clamped anywhere within the area of the ring. The spherical heads were turned of equal size, to fit the cups on the measuring rod. In the first instance stout posts with brass-headed nails in their centres were used for terminals.

The method of procedure was as follows. A tripod was set up over the first post and the spherical head clamped, with the plumb bob over the brass nail. A correction was applied for any inclination of the ring. A piece of string 60 feet in length with tabs every 6 feet was stretched on the ground in the direction of the base line, to facilitate the setting of the tripods. B tripod was set over the first tab and C tripod over the second, with the heads unclamped. The measuring rod was now placed upon the heads of A and B tripods. The head of B tripod being unclamped was free to take the position necessary to fit the cup at the end of the rod.

After lining, B head was clamped and the clinometer read off. Then the same process was repeated on B and C tripods.

A tripod was set forward over the tab in advance of C, and so on to the end of the base.

The following results were thus obtained in 1883 from three measurements of the same base line :—

| | Feet. | Differences. | $\mu$ | in. |
|---|---|---|---|---|
| I. | 442·635 | 15 | 34 | $\frac{1}{5}$ |
| II. | 442·612 | 8 | 18 | $\frac{1}{10}$ |
| III. | 442·612 | 8 | 18 | $\frac{1}{10}$ |
| | 442·620 | 10 | 23 | $\frac{1}{8}$ |

N.B.—$\mu$ = millionths of the whole distance.

These results were so encouraging that I determined to go a step further, and secure results of an accuracy of not less than 1 in 100,000.

For this purpose I made another rod, 10 feet in length, of well-seasoned pine, with a T section, but with an opening $\frac{1}{2}$ inch square from end to end, through which a steel rod $\frac{1}{4}$ inch diameter passed. The steel rod was firmly attached at each end to brass plates with spherical cups, and two thermometers were also attached to the rod. Fresh terminals were used, consisting of iron castings, with $\frac{1}{2}$-inch vertical holes in their centres, buried in the ground, the surface of the ground being made good by iron box frames and lids.

Adopting precisely the same method as before, the following results were obtained in 1886 :—

| | Feet. | Differences. | $\mu$ | in. | Feet. | Differences. | $\mu$ | in. |
|---|---|---|---|---|---|---|---|---|
| I. | 836·33022 | 461 | 5·5 | $\frac{1}{18}$ | 442·89724 | 72 | 1·6 | $\frac{1}{111}$ |
| II. | 836·33786 | 303 | 3·6 | $\frac{1}{28}$ | 442·89682 | 114 | 2·3 | $\frac{1}{71}$ |
| III. | 836·33640 | 157 | 1 9 | $\frac{1}{52}$ | 442·89981 | 185 | 4·2 | $\frac{1}{45}$ |
| | 836·33483 | 307 | 3·7 | $\frac{1}{27}$ | 442·89796 | 124 | 2·8 | $\frac{1}{88}$ |

Thus a greater accuracy than 1 in 100,000 was obtained.

The 10-feet measuring rod was afterwards further improved by making the wood portion of square box section, and supporting the steel rod on rollers along the centre of the box. Simple means were also adopted for measuring intermediate lengths with an accuracy of 1-100th of an inch. The thermometers were bedded to the steel rod with mercury amalgam. A detached thermometer was also placed inside the box near to one of the other thermometers, and the steel rod was blackened throughout its whole length to increase its thermal conductivity, the weight of the whole rod being about 12 lbs.

In order to determine the exact value of the measuring rod I have designed a variable end standard, which Messrs. Troughton and Simms have constructed for me.

It consists of a cold-drawn steel tube $1\frac{1}{4}$ inch external diameter, with a telescopic or sliding piece at one end having a range of 1 inch. The ends are parallel plane surfaces. By means of a vernier, scale, and reading microscope, the position of the telescopic end in reference to the tube is easily determined by estimation to 0·0005 inch, and with care to 0·00025, the reading being to 0·001.

The tube is supported in a stout mahogany box at two points, on a roller at one, and suspended by a vertical arm and cross-piece at the other. The box is provided with brass brackets at each end, by means of which it rests upon the spherical heads. One bracket has a spherical cup, the other bracket a cylindrical groove.

By means of suitable screws and springs the plane ends of the steel tube are brought into firm contact with the spherical heads, so that the centres of the spheres lie in the axis of the tube. The temperature of the tube is indicated by two thermometers.

Most of the comparisons have been taken on two iron brackets firmly attached to the stone wall of the observatory, but I have constructed a wooden bench carrying two iron plates at each end, connected by two steel rods from end to end in such a manner as to withstand the springs of the steel tube or standard 10-feet measure. In this way I have got results about 0·0002 inch less than when the comparisons were made on the iron brackets.

Six sets of comparisons, consisting of five each set on the iron brackets, gave 10·00296 feet as the value of the measuring rod, with a mean error of each set of 0·000015 foot. Another six sets on different days gave 10·002951 feet as the value, with a mean error of each set of 0·000012 foot. With greater reading power I have no doubt that one set of comparisons would give the value of the rod to 0·0001 inch or 0·00001 foot.

The average difference of the two thermometers on the 10-feet standard in 125 comparisons was 0°·93 F., and the 10-feet measuring rod under similar circumstances 0°·69 F. The difference between the attached and detached thermometers adjoining one another on the measuring rod in 145 comparisons was 0°·16 F., showing a close approximation of the steel rod to the temperature of the air. Two persons can make five comparisons in $12\frac{1}{2}$ minutes.

Experiments for expansion gave a coefficient of 61·5 ten-millionths for 1° F. for both rods, with a probable error of 1·0 ten-millionth. One hundred feet have been set off with the measuring rod eight times with a mean error of 0·0005 foot, showing that the apparatus is capable of doing reliable work to 1 in 200,000. One hundred yards can be measured easily in one hour with one assistant.

The accompanying drawings will make the above description clear.

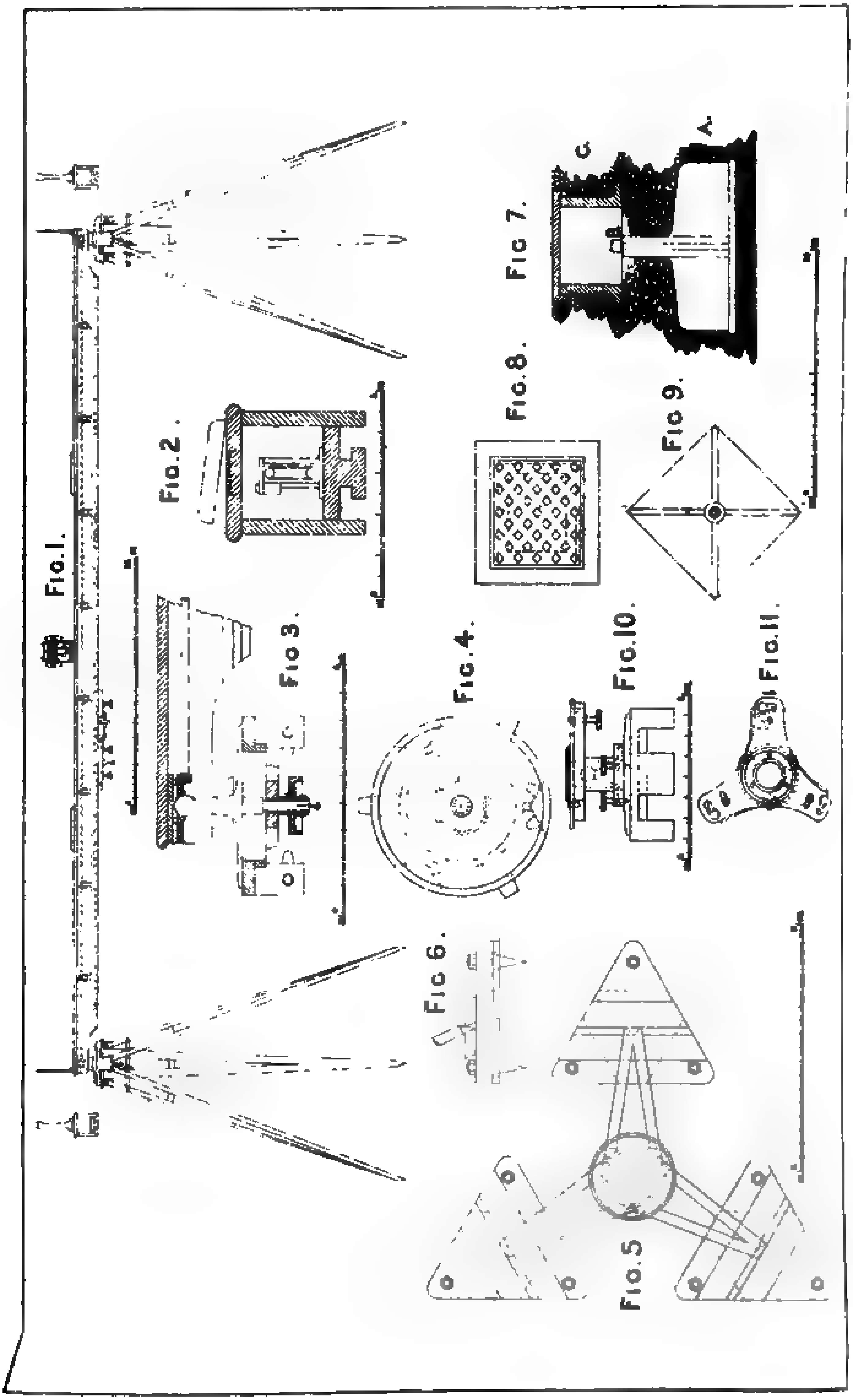
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5
Fig. 6.
Fig. 7.
G
A
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11.

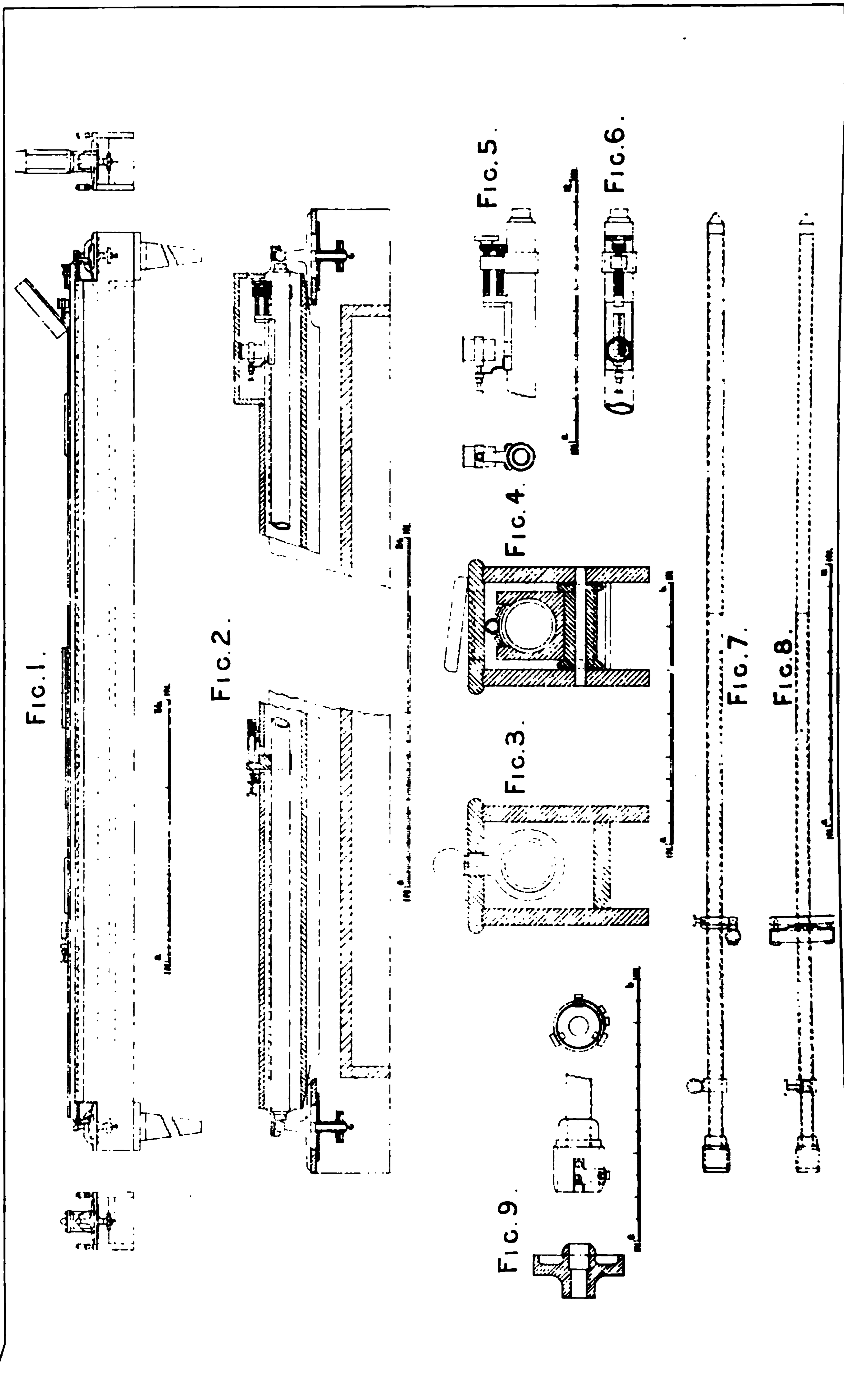
FIG. 1.
FIG. 2.
FIG. 3.
FIG. 4.
FIG. 5.
FIG. 6.
FIG. 7.
FIG. 8.
FIG. 9.

*Plate 1.*

Fig. 1 is the measuring rod of square box section resting on two tripods.

Fig. 2 is a section of the rod. The steel rod is indicated in both drawings passing through the middle of the box on rollers. At each end of the rod are sights for lining. In the centre is the clinometer, and between these the two thermometers.

Underneath the rod is a sliding piece, with clamps and slow motion and hook for plumb bob for measuring part lengths, the rod being divided every six inches, an ivory scale divided on both edges giving intermediate lengths to the hundredth of an inch.

Fig. 3 shows the end of the rod and the top of the tripod in section, and fig. 4 the top of the tripod in plan.

Figs. 5 and 6 show a method of supporting the tripods so as to facilitate the levelling of the rings, by moving the feet along the grooves tangentially, and thus tilting the rings to any desired position.

Fig. 7 shows the terminal mark, consisting of an iron casting A, surmounted by a brass step with cap at B. C is the box frame and lid for making good the surface of the ground.

Fig. 8 is a plan of C.

Fig. 9 is a plan of A.

Figs. 10 and 11 show a pedestal suitable for supporting a theodolite centrally over the spherical head on one of the tripods.

*Plate 2.*

Fig. 1 shows the standard 10-feet rod resting upon two spherical heads upon the wooden comparing bench.

Fig. 2 shows the above in longitudinal section.

Figs. 3 and 4 are sections of the rod.

Figs. 5 and 6 show the telescopic end of the steel tube, with reading microscope and adjusting screws.

Figs. 7 and 8 show a telescopic tubular rod, which is more convenient than the plumb bob. The lower end is conical, and fits into the brass step on the terminal. The upper end is cylindrical, and embraces the spherical portion of the milled head as shown in section, fig. 9. The rod will then rotate on these two centres, and by means of the attached level the vertical position is easily found with considerable accuracy.

## *Observations of Comet b 1887 (Brooks) made at the Royal Observatory, Greenwich.*

*(Communicated by the Astronomer Royal.)*

The observations were made with the East or Sheepshanks Equatorial, aperture 6·7 inches, by taking transits over two cross wires at right angles to each other, and each inclined 45° to the parallel of Declination.

1887 *Comet b (Brooks).*

| Greenwich Mean Solar Time. | | | | Observer. | ☄−✱ R.A. | Corr. for Par. and Refraction in R.A. | ☄−✱ N.P.D. | Corr for Par. and Refraction in N.P.D. | No. of Comp. | Apparent R.A. | Apparent N.P.D. | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1887 | h | m | s | | m s | s | ′ ″ | ″ | | h m s | ° ′ ″ | |
| March 13 | 8 | 12 | 24 | A. D. | −2 1·17 | +0·30 | + 9 9·7 | −1·7 | 3 | | | *a* |
| 13 | 8 | 30 | 1 | | −2 36·50 | +0·30 | − 0 31·6 | −1·9 | 3 | 3 57 48·90 | 45 37 34·7 | *b* |
| 16 | 11 | 47 | 59 | H. T. | −0 44·64 | +0·30 | + 5 24·3 | −3·9 | 5 | 4 4 4·53 | 48 15 50·6 | *c* |
| 18 | 8 | 17 | 5 | H. T. | +0 22·12 | +0·20 | − 3 43·9 | −2·1 | 6 | 4 7 33·75 | 49 44 29·1 | *d* |
| 23 | 8 | 0 | 51 | H. | +1 20·66 | +0·20 | + 4 35·8 | −2·1 | 5 | 4 16 17·28 | 53 26 25·9 | *e* |
| 23 | 8 | 35 | 56 | | −1 48·70 | +0·20 | − 8 25·7 | −2·4 | 3 | 4 16 20·71 | 53 27 15·9 | *f* |
| 24 | 9 | 58 | 27 | T. | −0 23·31 | +0·30 | − 1 22·9 | −3·0 | 8 | | | *g* |
| 24 | 10 | 11 | 34 | | +2 22·50 | +0·30 | − 2 7·8 | −3·1 | 1 | | | *h* |
| 24 | 10 | 11 | 34 | | +2 1·50 | +0·30 | −10 2·8 | −3·1 | 1 | 4 18 11·32 | 54 11 45·0 | *i* |
| 27 | 10 | 11 | 3 | H. T. | −0 31·37 | +0·30 | − 1 40·9 | −3·2 | 6 | | | *j* |

*Mean Places of Comparison Stars.*

| | Star's Name. | R.A. 1887·0 | N.P.D. 1887·0 | Authority. |
|---|---|---|---|---|
| | | h m s | ° ′ ″ | |
| *a* | Arg. Zone +44° 859 | 3 59 47 | 45 29 | Bonn Observations, Vol. V. |
| *b* | W. B. (2) III. 1241 | 4 0 25·52 | 45 38 8·5 | Weisse's Bessel (2) |
| *c* | W. B. (2) IV. 8 | 4 4 49·29 | 48 10 29·0 | Weisse's Bessel (2) |
| *d* | *f* Persei | 4 7 11·88 | 49 48 13·5 | Greenwich Observations, 1886 |
| *e* | W. B. (2) IV. 259 | 4 14 56·92 | 53 21 49·2 | Weisse's Bessel (2) |
| *f* | W. B. (2) IV. 337 | 4 18 9·69 | 53 35 41·3 | Weisse's Bessel (2) |
| *g* | Arg. Zone +35° 858 | 4 15 44 | 54 13 | Bonn Observations, Vol. IV. |
| *h* | W. B. (2) IV. 287 | 4 16 10·03 | 54 21 48·1 | Weisse's Bessel (2) |
| *i* | Arg. Zone +35° 865 | 4 18 27 | 54 12 | Bonn Observations, Vol. IV. |
| *j* | Arg. Zone +33° 871 | 4 23 23 | 56 14 | Bonn Observations, Vol. IV. |

The observations are corrected for parallax and refraction. The initials H. T., A. D., T., H. are those of Mr. Turner, Mr. Downing, Mr. Thackeray, and Mr. Hollis respectively.

## *Lunar Occultations on March* 29, 1887. By C. Leeson Prince.

I observed the occultations of five stars this evening under very favourable conditions.

The grey light of the non-illuminated portion of the Moon was remarkably distinct at the limb, and its gradual approach to each star could not be watched with greater exactness.

| | Local Sidereal Time. Disapp. | Reapp. |
|---|---|---|
| | h m s | h m s |
| $\theta^1$ Tauri ... ... | 9 46 17·5 | 10 42 6 |
| $\theta^2$ „ ... ... | 9 55 22 | 10 36 56 |
| A small star ... ... | 10 0 47·5 | |
| A bright red star ... ... | 10 31 23 | |
| B.A.C. 1391 ... ... | 10 44 54·5 | |

About three or four seconds before occultation of the three principal stars I noticed a diffraction phenomenon which I do not recollect to have previously observed, viz. that as the Moon approached each star the brilliancy of the latter completely obliterated the grey tint of the lunar surface at the point of contact, and a dark semicircle appeared thereupon up to the moment of disappearance, which in the case of each star was quite instantaneous.

The reappearance of $\theta^1$ and $\theta^2$ *Tauri*, so far as I could judge, was not so immediate.

I employed my Equatorial telescope of 6·8 inches aperture and 12 feet focal length, mag. power 144.

*The Observatory, Crowborough, Sussex:*
*April* 2, 1887.

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*Errata.*

In General Tennant's paper, "The Orbit of Comet II., 1883," page 26, line 11,

$$\textit{for } L = 114^\circ\ 39'\ 01''\!\cdot 9$$

$$\textit{read } I = 114\ \ 59\ \ 01\cdot 9$$

In General Tennant's paper, "Notes on Reflecting Telescopes," page 258, line 8,

$$\textit{for } Ap = \frac{a}{16} = 2a + \frac{a}{16}\left\{24v^2 + 9v^4 + \frac{7}{2}v^6 + \&c.\right\}\frac{1024 + 640v^2 + 96v^4 + 4v^6 + v^8}{32 - 4v^2 - 3v^4}$$

$$\textit{read } Ap = \frac{a}{16}\cdot\frac{1024 + 640v^2 + 96v^4 + 4v^6 + v^8}{32 - 4v^2 - 3v^4} = 2a + \frac{a}{16}\left\{24v^2 + 9v^4 + \frac{7}{2}v^6 + \&c.\right\}$$

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. XLVII. MAY 13, 1887 No. 7

J. W. L. GLAISHER, M.A., F.R.S, President, in the Chair.

W. Austin Ashe, Director of the Observatory, Quebec; and
Gustavus William Nicolls, Caixa 162, Pernambuco, Brazil,

were balloted for, and duly elected Fellows of the Society.

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*On the Images formed by Reflecting Mirrors, and their Aberration.*
By the Hon. Lord McLaren.

The application of reflecting telescopes to photography renders it desirable that their suitability for large fields should be tested by an accurate investigation of the caustic images produced by the reflection of oblique pencils from their surfaces. This is the purpose of the present paper.

It has been suggested that for large fields a mirror of spherical figure possesses some advantages over that of the parabolic form, on the ground that the spherical mirror, while it does not bring any parallel pencil to an accurate focus, reflects always a circular image, and gives images of equal intensity at all angles. The present investigation shows that for fields of any angle likely to be required in practice—say for any angle under two degrees—the lateral aberration of the paraboloid is inconsiderable. But it also brings out a variation of focal length for different distances from the centre of the field, which even for a field of 2° is considerable. It will be shown in the sequel that the cycloidal mirror possesses some advantages in this respect over mirrors of the parabolic type.

The form of the caustic surface produced by direct reflexion from a spherical surface is well known: it is, near the image, a

cone generated by the revolution of an epicycloid, and presents its apex, or cusp, to the observer's eye. I have not found, however, in any work accessible to me, a solution of the problem of the caustic surfaces produced by the reflexion of oblique pencils from a paraboloid. Sir William Hamilton, in his great Memoir on the "Theory of Systems of Rays,"* finds expressions for the caustics formed by reflecting surfaces of any form. The distinguished author has not shown how these expressions are to be integrated for parabolic reflecting surfaces, and I am not aware that his differential equations have been integrated for the general equation of a surface of the second degree.

The solution which I offer for the case of a parabolic mirror is obtained in a different way, and is perhaps of some practical interest. It will be seen that for rays of any inclination to the axis of symmetry the caustic is a curve resembling a parabola, confocal with the reflecting surface, and having its axis inclined to that of the reflector at an angle depending on the inclination of the ray. The equation of the caustic curve, referred to its own axis, is

$$\rho^{\frac{1}{3}} \cos \frac{\theta}{3} = a^{\frac{1}{3}},$$

The small arc of the caustic which constitutes the image of a non-central star is a diminished copy, or nearly so, of the arc of the reflector, but turned round so as to lie nearly in the line of sight. The image of the whole field is convex to the observer's eye, and is aplanatic only in this sense, that equal arcs of the heavens are represented by equal arcs in the image of the field.

CASE I.—*To find the equation to the caustic of the parabola for parallel rays in the principal plane.* (See Plate 7.)

Let $S_1S_2S_0$ be an axial section of the parabolic reflecting surface in the plane of reflection, O the focus and origin of polar coordinates.

$S_1O$, $S_2O$ two consecutive vectors.

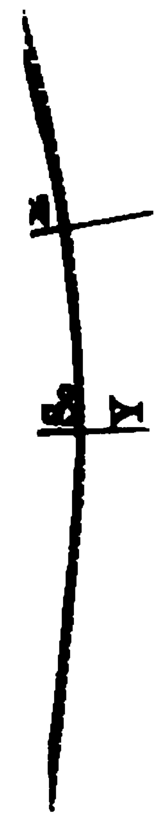
$S_1P_1$, $S_2P_2$ two consecutive reflected rays, on which let the perpendiculars $OP_1$, $OP_2$ be let fall from the origin.

> $S_0O$ (or X) is the axis of the parabolic reflecting surface.
> $S_0P_0$ the reflected ray proceeding from the vertex, and making with the axis an angle $= (\phi)$.
> $OP_0$ is the perpendicular on $S_0P_0$ from O.

Then the curve $P_1P_2P_0$ represents the locus of the intersections of the reflected rays with the perpendiculars drawn from O, and the curve $C_1P_0C_2$ represents the caustic, or locus of the intersections of consecutive reflected rays.

Let the axis of the reflecting surface be the reference line for the polar equation $f(\rho\,\theta)$ of the parabola, and also for the

* *Trans. Roy. Irish Acad.* Vol. XV.



respective polar equations $f'(\rho'\,\theta')$ and $f''(\rho''\,\theta'')$, of the curve $P_1P_2P_0$ and the curve $C_1P_0C_2$.

Then, because the incident pencil is a pencil of parallel rays, all the rays which are incident on the parabola at points $S_1$, $S_2$, &c. are inclined at the same angle $(=\phi)$ to the lines parallel to X which pass through these points; and all the reflected rays are inclined at the same angle $(=-\phi)$ to the corresponding vectors.

Or, if $(\chi)$ be the angle between the normal and the $x$ coordinate at any point $S_1$,
$(-\chi)$ the angle between the normal and the radius vector at the same point,
$(\chi+\phi)$ will be the angle of the incident ray at point $S_1$,
$-(\chi+\phi)$ will be the angle of the reflected ray at the same point.

In other words, all the reflected rays $S_1P_1$, $S_2P_2$, &c. make equal angles $(=-\phi)$ with the vectors passing through $S_1$, $S_2$, &c.

Therefore, in the series of triangles $OS_1P_1$, $OS_2P_2$, &c. all the angles at $S_1$, $S_2$, &c. are $=\phi$;

and all the angles at $P_1$, $P_2$, &c. are by construction right angles.

Therefore the remaining angles $S_1OP_1$, $S_2OP_2$, &c. are each $=90^\circ-\phi$.

If $\theta$ be the angle between the reference line and any vector, $OS_1$ of the parabola, then

$$\theta'=\theta+(90^\circ-\phi)\,^*$$

will be the angle between the reference line and the corresponding vector $OP_1$ of the curve $P_1P_2P_0$. Also

$$\text{vector } OP_1=\text{vector } OS_1\times\sin\phi,$$

or

$$\rho'=\rho\sin\phi.$$

Now, if the reference line for the curve $P_1P_2P_0$ be turned round to $OP_0$, while the reference line for the parabola $S_1S_2S_0$ is unchanged, then, for any correlative points $S_1P_1$ in the two curves whose current coordinates are $(\theta\rho)$ and $(\theta'\rho')$, we have

$$\theta'=\theta,$$

and

$$\rho'=\rho\sin\phi=\rho\times\text{constant}.$$

The curves are therefore similar in figure, and the curve $P_1P_2P_0$ is a parabola with parameter

$$4a'=4a\sin\phi \quad \ldots\ldots\ldots\ldots \quad (a)$$

where $(4a)$ is the parameter of the reflecting curve.

* In the figure $\theta$ is negative, being in the fourth quadrant.

The equation of the curve $P_1P_2P_0$ may be thus written :

$$\rho'^{\frac{1}{2}} \cos \tfrac{1}{2}\theta' = a'^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

From this construction the equation of the caustic may be immediately deduced. By construction the derived parabola, $P_1P_2P_0$, is the locus of intersections of perpendiculars drawn from O to the reflected rays. By definition the reflected rays are tangents to the caustic curve, $C_1P_0C_2$, and the caustic is thus the first negative pedal of the derived parabola.

The equation of the caustic is deduced as follows:

By a known property of pedal curves, if

$$\rho'^{m} \cos m\theta' = a^{m}$$

be the equation to a curve,

$$\rho''^{\frac{m}{m+1}} \cos \frac{m}{m+1} \theta'' = a^{\frac{m}{m+1}}$$

is the equation of its first negative pedal.*

Hence, from the expression for the derived parabola [Equation (*b*)]

$$\rho'^{\frac{1}{2}} \cos \tfrac{1}{2}\theta' = a'^{\frac{1}{2}}$$

we may at once write the equation of the caustic.

It is

$$\rho''^{\frac{1}{3}} \cos \tfrac{1}{3}\theta'' = a'^{\frac{1}{3}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

where $a'$ is the prime vector in both curves, and is $= a \sin \phi$. The caustic touches the pedal, or derived parabola, at the vertex $P_0$ For any value of $\theta'$ not greatly exceeding 90° the caustic lies within the pedal parabola.

When $\theta'' = 270°$, $\cos \frac{1}{3}\theta = 0$, and $\rho''$ becomes infinite.

The caustic is evidently a looped curve, with branches intersecting at the point where $\theta'' = 180°$, and tending to ultimate parallelism with a line at right angles to its axis of symmetry.

*Locus of Caustics.*—If we suppose the inclination of the pencil to vary we shall have as many caustic curves as there are radiant points on the celestial arc, the quantity $a'$ representing in each case the distance of the star image from the centre of the telescopic field. Before proceeding to the analysis for the surface of revolution, it may be noticed that in the parabolic mirror the locus of the vertices of the caustic curves is the point $(P_0)$, being the angular point of the right-angled triangle $OP_0S_0$. It therefore lies on a circle (shown in the diagram) whose diameter is the focal length, $OS_0$, and radius $= \frac{1}{4}$ radius of curvature of the parabola at the vertex. That is to say, all the foci for pencils of different degrees of obliquity (or star-images of variable distances) lie on the circle; and all the

* Williamson, *Differential Calculus*, p. 231.

star-images in the field lie on a spherical surface whose radius $=\frac{1}{4}$ radius of curvature of parabola at vertex.

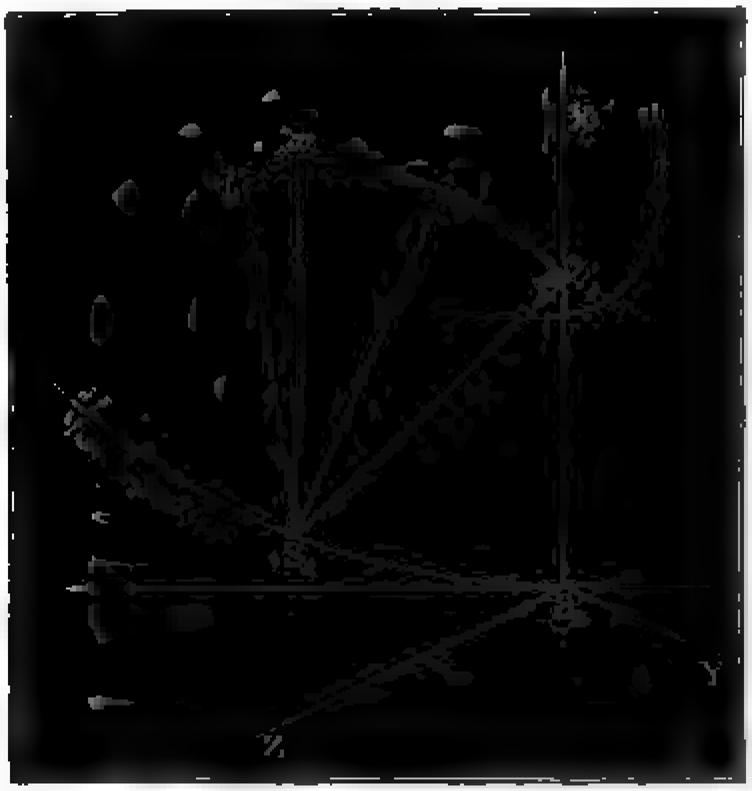



Fig *a*.

CASE II. *Caustic Surface for the Paraboloid of Revolution.*—The caustic surface may be obtained by investigating the equation of the plane curve for any plane section of the paraboloid passing through the axis or at right angles to it.

Except in the case already considered, neither the incident nor the reflected ray lies in the plane of the section, nor do any two consecutive reflected rays lie in the same plane. The solution is therefore a little complicated, but it may be found by projective geometry commencing with the following preliminary proposition.*

*The normal, the abscissa of the paraboloid, and the incident ray* at any point S constitute a solid angle, whose six edges and angles are respectively equal to those of the solid angle formed by *the normal, the vector, and the reflected ray*. (See Figure *a*.)

If we denote these five lines by their initial letters we have

| | |
|---|---|
| normal $=n$ | abscissa, parallel to $X=x$ |
| incident ray $=i$ | radius vector $=\rho$ |
| reflected ray $=r$ | S is the incident point. |

The same letters, $n$, $x$, $i$, $r$, and $\rho$, also denote the points of

* In what follows the reference plane for projections is a section through the axis of the paraboloid, and having any required inclination to the principal plane. It is assumed that the reflected rays intersect in some regular curve.

the two spherical triangles from which the angles at S are to be deduced.

*To show that the solid angle* $i, n, x$ *is equal to the solid angle* $\rho n r$.—The three lines $x$, $n$, $\rho$ are in one and the same plane, viz. the given axial section of the paraboloid, and angle $n\,S\,x$=angle $n\,S\,\rho$. Also the three lines $i\,n\,r$ are in one plane, being the plane of reflexion; and, by the law of reflexion, angle $i\,S\,n$=angle $n\,S\,r$. Now these equal angles are proportional to the corresponding sides of the two spherical triangles; also the contained angles formed by the intersection of the plane faces $i\,n\,r\,S$, $x\,n\,\rho\,S$ are equal. Therefore the remaining sides and angles are equal.

$$\therefore \angle\, rS\rho = \angle\, iSx = \phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d)$$

$$\angle \text{ between faces } rS\rho,\, xS\rho = \angle \text{ between faces } iSx,\, xS\rho = \psi \quad . \quad . \quad (e)$$

These equations are fundamental. Equation ($d$) is independent of the particular section It affirms that for any point S on the surface of a paraboloidal mirror the plane angle ($rS\rho$) between the reflected ray and the radius vector is *invariable*, and is equal to $\phi$, the inclination of pencil to mirror axis.

In Equation ($e$) it is easily seen that the quantity $\psi$ is the angle between a given axial section and the principal plane. This equation affirms that for any point S on the given mirror section the inclination of the plane faces $r_1S_1\rho_1$, $r_2S_2\rho_2$, &c. to the plane of the section is constant, and equal to $\psi$.

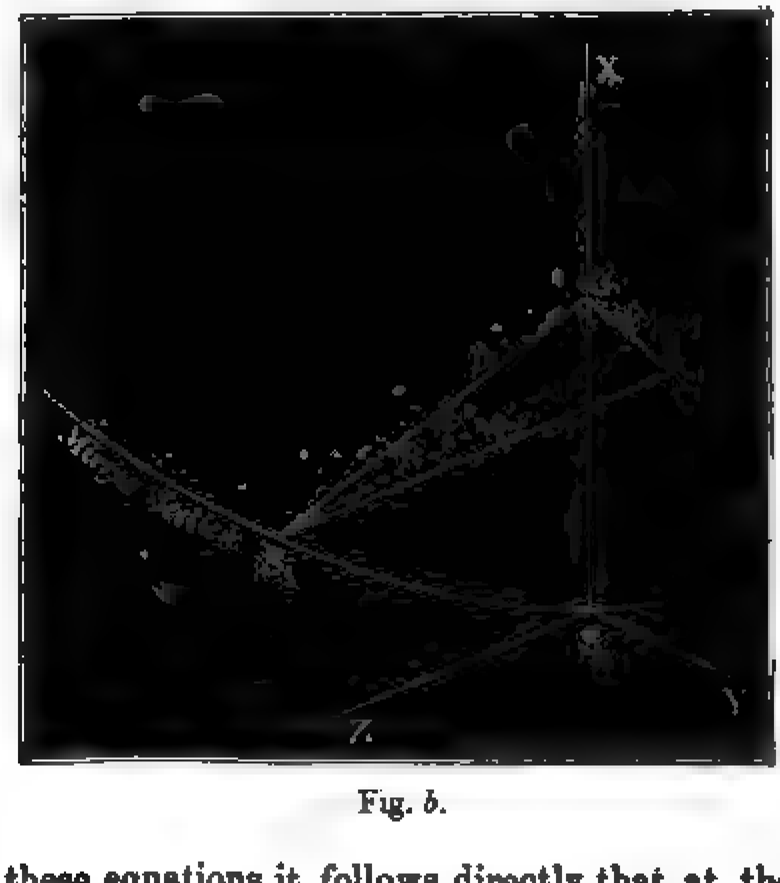



Fig. $b$.

From these equations it follows directly that at the variable point S the projection of the reflected ray on the plane of the section makes a constant angle ($\phi'$) with the radius vector, and

also that the projection of the reflected ray makes a constant angle with the reflected ray itself. (See Figure *b*, where $c_1$ is a point in the caustic, and $c_1'$ a point in its projection on the plane of the axial section. $OS_1c_1'$.)

Because if we consider any of the solid angles formed at $S_1$, $S_2$, &c. by the vector, the reflected ray and the projection of the reflected ray (which may be denoted by $r'$), we see that its edges and angles are proportional to the angles and sides of a right-angled spherical triangle, of which one of the sides$=\phi$ and one of the angles (other than the right angle)$=\psi$. Now, as these quantities are the same for all the solid angles at $S_1$, $S_2$, &c. it follows that all the solid angles have their third edges and three angles respectively equal; or generally, for the solid angles at points $S_1$, $S_2$, &c. we have

Three edges respectively $=\psi$, $90°$, $90°-\psi$,

and three plane angles $\phi$, $\phi'$, and $\phi''$, whose equations are $\phi$, $=\angle$ between incident ray and $x$.

$$\tan\phi' = \tan\phi\cos\psi = \text{constant} \quad . \quad . \quad . \quad . \quad . \quad . \quad (f)$$

$$\sin\phi'' = \sin\phi\sin\psi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (g)$$

*To form the equation of the caustic curve in the plane of projection.*

With the same diagram and notation as in Case I., the plane of the paper is now the plane of the given axial section, making the angle ($\psi$) with the principal plane. The lines $AS_1$, $AS_2$, &c. are the projections of the parallel incident rays on the section. They are therefore also parallel, and make a constant angle $f(\phi\psi)$ with the corresponding *abscissæ*. $SP_1$. $SP_2$, &c. are the projections of the reflected rays, to which the perpendiculars $OP_1$, $OP_2$, &c. are drawn from the focus.

Then for any one of the points $S_1$, $S_2$, &c. we observe that the plane of projection intersects the plane of reflexion in the normal N; and it is evident that equal angles measured from N, in the plane of reflexion, are represented by equal angles in the plane of projection. Therefore the projections of the incident and reflected rays make equal angles with the normal at any point, $S_1$, $S_2$, &c. of the series. Then, as before, $\rho_1\theta_1$, $\rho_1'\theta_1'$, $\rho_1''\theta_1''$, are the current coordinates of the original and the two derived curves, whence we deduce the curve in the plane of projection identically as in Case I.

Angles $OS_1P_1$, $OS_2P_2$, &c. $=\phi'$ [$=$constant, by Equation ($f$)].

Angles $S_1P_1O_1$, $S_2P_2O_2$, &c. are by construction right angles. Therefore

Angles $S_1OP_1$, $S_2OP_2 = 90-\phi' =$ constant.

Hence $OP=OS \,.\, \sin\phi'$, or

$$\rho' = \rho\sin\phi' \qquad a' = a\sin\phi'$$

$\theta'$ (measured from its own axis $OP_0$) $=\theta$ (measured from $x$).

Hence the curve $P_0P_1P_2$, or derived parabola $f(\rho'\theta')$, is the locus of intersections of *perpendiculars on the projections of the reflected rays.*

Its parameter $$4a' = 4a \sin \phi'.$$

And finally the negative pedal of the derived parabola is the projection of the caustic of the given section, or *locus of intersections of the consecutive projections of the reflected rays.*

It is as before

$$f(\rho''\theta'') = \rho''^{\frac{1}{3}} \cos \frac{\theta''}{3} - a'^{\frac{1}{3}} = 0,$$

where, approximately,

$$a' = a \sin \phi \cos \psi.$$

We thus see that for any axial plane of the paraboloid the *projections* of the reflected rays form a caustic curve, having the same equation as the caustic curve in the principal plane.

By projective geometry two curves which are connected by a projective relation are of the same degree and the same class, and differ only in their constant coefficients.*

We therefore conclude that the equation of the caustic is of the same form as the equation of its projection, and its parameter only remains for determination.

*Caustic deduced from its Projection.*—The reflected ray from the vertex of the mirror is evidently common to all the axial sections. It is therefore invariable in position and magnitude. The prime vector $\dot{a}$ of the caustic deduced in the principal plane is necessarily also common to all the axial sections; because it is the line drawn from the origin to the extremity of the ray reflected from the mirror vertex. That is to say, for all axial sections of the mirror we have caustic curves, of the same form and with parameter invariable in length and position; and, therefore, if the axial section of the mirror is turned round, so as to generate a surface of revolution, the caustic curve also will generate a surface of revolution about its axis of symmetry.

*Circular Section of the Paraboloid.*—The result just obtained may be found more easily by considering a circular section of the mirror in the plane YZ.

In such a section let $\rho_1, \rho_2$, &c. be the vectors drawn from consecutive points $S_1$, $S_2$, &c. of the circular section to the focus O. They are evidently of equal length, and their integral is a right cone, having its vertex at O. Let $r_1$, $r_2$, &c. be consecutive reflected rays drawn from the same series of points $S_1$, $S_2$, &c.

Thenby Equation (*d*) (which is general for the whole reflecting surface) all the angles $\rho_1 S_1 r_1$, $\rho_2 S_2 r_2$, &c. (although lying in different planes) are equal to one another, being equal to the constant $\phi$.

* Cremona, *Projective Geometry*, Chap. II.

Let perpendiculars $OP_1$, $OP_2$ be drawn from O to the reflected rays $r_1$, $r_2$, &c. and we have

$$OP_1 = \rho_1 \sin \phi ;$$
$$OP_2 = \rho_2 \sin \phi = OP_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (h)$$

since all the vectors $\rho_1$, $\rho_2$, &c. of the circular section are equal.

The locus of P accordingly is a small circle, described on the surface of a sphere whose radius $\rho' = \rho \sin \phi$.

This small circle is the caustic, because the consecutive reflected rays are tangents to it.

If we now consider two opposite points of the mirror section in the plane of the luminous pencil we see that for one of these the point P lies outside the cone of vectors, and for the other it lies inside the cone. The line joining the two points P is a diameter of the caustic circle; and by drawing the diagram in perspective for two parallel circular sections of the mirror it will be seen that the caustic circles are parallel and co-axial. Their integral is therefore a surface of revolution whose equation is that of the caustic curve in the principal plane.

*Lateral Aberration.*—In the caustic of the parabola we have not to find a circle of least aberration, because at the focus the aberration is *nil*, and we have only to determine for any particular point or image the diameter of a section of the cone of rays through the plane of the field of view. The aberration, whether in a direction radial or transversal to the field, is to be obtained from the equation to a section of the surface, in terms of the focal length ($a$), the semi-arc of mirror ($\theta$), and the inclination of pencil ($\phi$).

In the principal plane the required aberration is the difference of the distances of the *surface of caustic* and its tangent from centre of field, or focus of paraboloid.

The latter

$$= a'' \sec \theta, \text{ where } a'' = a \sin \phi.$$

The former

$$= \rho'' = \frac{a''}{\cos^3(\frac{1}{3}\theta)} = a'' \sec^3\left(\frac{\theta}{3}\right).$$

Therefore

$$\text{aberration} = a \sin \phi \left[\sec \theta - \sec^3\left(\frac{\theta}{3}\right)\right] \quad . \quad . \quad . \quad . \quad . \quad (k)$$

$\theta$ is determined by the aperture of mirror.

The rays proceeding from that half of the caustic surface which lies on the negative side of its prime vector constitute the right half of the pencil which enters the eye-piece; those proceeding from the positive side of the prime vector constitute the left half of the visual pencil. It is evident that near the centre of the field the images are symmetrical.

Except near the centre of the field there will obviously be a greater dispersion of the rays in the plane XZ than in

the plane XY of the incident pencil; and the diameter of the visible image will, apparently, be smaller in proportion to the dispersion.* If we assume that the visual pencil, in the direction XZ, is only effective to the extent of one-half of its angular divergence, then we have for this aberration the quantity

$$\psi = \sqrt{\tfrac{1}{2}},$$

and

$$a'' = a \sin\left(\frac{\phi}{\sqrt{2}}\right).$$

Therefore, by Equation ($k$), we have, in a direction transverse to radius of field,

$$\text{lateral aberration from centre of image} = a \sin\left(\frac{\phi}{\sqrt{2}}\right)\left[\sec\theta - \sec^2\left(\frac{\theta}{3}\right)\right] \quad . \quad (l)$$

The breadth of the image will be twice this quantity.

*Example of Computation of Lateral Aberration.*

Assume focal length = 16 feet = 192 inches = ($a$) and diameter of mirror = 24 inches.

The semi-arc of mirror will be about $3° \; 30' = (\theta)$

For a star 1° from centre of field, $1° = (\phi)$

$$\log\sin\phi = 8\cdot2419$$

$$\frac{\phi}{\sqrt{2}} = \frac{1°}{1\cdot4142} = 0°\cdot7072 = 43'$$

$$\log\sin\frac{\phi}{\sqrt{2}} = 8\cdot0972$$

$$\sec\theta = \sec 3° \; 30' \qquad = 1\cdot0019$$

$$\left.\begin{aligned} \sec\tfrac{1}{3}\theta = \sec 1° \; 10' : \log\sec &= \cdot00009 \\ \log\sec^2\left(\frac{\theta}{3}\right) &= \cdot00027 \end{aligned}\right\} \; . \; \sec^2\left(\frac{\theta}{3}\right) = 1\cdot0006$$

$$\sec\theta - \sec^2\left(\frac{\theta}{3}\right) = 0\cdot0013 = f \text{ (secant).}$$

Then

(1) In the principal plane by Equation ($k$) we have

$$\log 192 \text{ inches} = 2\cdot2833$$

$$\log\sin\phi = 8\cdot2419$$

$$\log f \text{ (secant)} = \log 0\cdot0013 = -3\cdot1139$$

$$\log \text{lateral aberration} = -3\cdot6391$$

$$\text{lateral aberration} = \cdot0044 \text{ inch.}$$

* Since this paragraph was written the writer has found, by making a large scale perspective drawing of the course of the rays, considered as tangents to the caustic surface, that the converging pencils are apparently truly symmetrical cones, and that their images are therefore *round*. This agrees with the results obtained experimentally by Mr. Howard Grubb (*Monthly Notices* for April, p. 310); and it is evident from the equations that, if the images are circular near the centre of the field, they will be circular through its entire extent, provided the images are received on a concave plate of the proper curvature, as suggested in Mr. Grubb's paper.

(2) In the transverse plane by Equation ($l$) we have

$$\begin{array}{rr} \log 192 & 2\cdot2833 \\ \log \sin \frac{\phi}{\sqrt{2}} & 8\cdot0972 \\ \log 0\cdot0013 & -\underline{3\cdot1139} \\ \log \text{aberration} = & -3\cdot4944 \end{array}$$

transverse lateral aberration from centre of image = ·0031 inch

transverse diameter of image = ·0062 inch.

## III. *Elliptic and Hyperbolic Reflecting Surfaces.*

Although the writer has not been able as yet to obtain an exact solution of the caustic for parallel rays incident on an elliptic surface, it may be here mentioned that if, in the case of the ellipse, a similar figure to that of Case I. in this paper be drawn with divergent and convergent pencils, making a given angle with the focal pencils, the locus of intersections of perpendiculars on the reflected pencil will be a small ellipse placed obliquely to the primary ellipse, and the caustic will be the first negative pedal of the derived ellipse. The divergent pencil traced backwards will be found to proceed from a radiating surface conjugate with the caustic surface. The caustic curves thus derived do not differ sensibly from the caustic of the parabola when they are represented graphically, and from the manner of their derivation they are obviously curves involving the cubic radical. It would add needlessly to the bulk of this paper to give the demonstration for the case of the elliptic caustic. By drawing the diagram with divergent and convergent pencils, and using the same notation and analysis as in Case I., the reader will have no difficulty in finding that the caustic of the divergent pencils is the first negative pedal of an ellipse whose axis is inclined to the minor axis of the reflecting ellipse at the angle ($\phi$) which the divergent pencil makes with the major axis. The same notation and analysis gives for the hyperbola, with converging incident pencils, and diverging reflected pencils, a caustic whose equation is the first negative pedal of a small hyperbola inclined to the reflecting hyperbola as in the case of the ellipse.

The relation found in Case I. between the caustic of the parabola and the equation of the parabola itself is thus shown to be only a limiting case of a more general theorem which includes all curves of the second degree. For if in the case of the ellipse, for example, the major axis be supposed infinite, then the converging pencil (whose rays are supposed to make a constant angle with those of a focal pencil) becomes a pencil of parallel rays having the given inclination to a pencil parallel to the axis of the reflecting surface.

IV. *Cycloidal Surfaces of Revolution.*—The investigation of the conditions necessary to the production of a perfect image by reflexion has led to the conclusion that these conditions are better fulfilled by the cycloid than by the parabola. This results from two well-known properties of this curve: (1) the base or line on which the generating circle rolls bisects all the radii of curvature; (2) equal linear intervals measured along the base from its centre correspond to equal angles between the radii of curvature.

From the *first* condition it results that, whatever may be the angular extent of the field of view, the geometrical foci of the images lie on the base-line of the cycloid or on the base-plane of its figure of revolution.

From the *second* condition it results that the field of view is a true stereographic projection of an area of the celestial sphere, equal intervals of arc in the sphere being represented by equal straight lines in the field of view.

*Caustic of the Cycloid.*—Consider first the case of a direct pencil parallel to the axis of symmetry of the mirror (represented in the left quadrant of the plate). The figure represents an axial section, the base being parallel to the axis of ($x$), and the axis of symmetry parallel to ($y$).

$I_1S_1$, $I_2S_2$, &c. are the incident rays.

$N_1S_1$, $N_2S_2$, &c. the normals.

$P_1S_1$, $P_2S_2$, &c. the reflected rays.

$f(x\ y)$ denotes the equation of the reflecting surface.

$f(x'\ y')$ the equation of the caustic.

$I_1S_1N_1$, $I_2S_2N_2$ are the angles which the normals make with lines parallel to the axis of $x$.

Then in the equation of the reflecting surface

$$I_1S_1N_1 - I_2S_2N_2 = \delta \tan^{-1}\left(\frac{dx}{dy}\right).$$

In the equation of the caustic $I_1S_1P_1$, $I_2S_2P_2$ are the angles which its tangents make with the axis of $x$. And because $I_1S_1P_1$, $I_2S_2P_2$ are the sums of the angles of incidence and reflexion

$$I_1S_1P_1 - I_2S_2P_2 = 2(I_1S_1N_1 - I_2S_2N_2),$$

or

$$\delta \tan^{-1}\left(\frac{dy'}{dx'}\right) = 2\delta \tan^{-1}\frac{dy}{dx}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

That is, the curvature of the caustic, at $P_1$, measured by the deflection of its tangent for unit increment of arc is double the curvature of the reflecting surface at the corresponding point $S_1$, measured by the deflection of its normal for an equal increment of arc.

If $\phi_1$ $\phi_2$ be the angles between consecutive normals to the cycloid and the relative incident rays (parallel to $y$),

$\phi_1'$ $\phi_2'$ the angles between the same normals and the base $x$

$$\phi_1-\phi_2=\phi_1'-\phi_2'.$$

If $\theta_1$ $\theta_2$ be angles between the incident rays and the reflected rays which are tangents to the caustic

$\theta_1'$ $\theta_2'$, the angles made by the normals to the caustic with the base

$$\theta_1-\theta_2=\theta_1'-\theta_2'.$$

Therefore, from Equation ($z$), we have

$$\theta_1'-\theta_2'=2(\phi_1'-\phi_2').$$

We may now directly compare the angles made by the normals of the two curves with the base-line. If we make the base-line the reference-line for angular measure, then at the point O, where the cycloid and the caustic are in contact, $\phi'=0$, $\theta'=0$, and for any other position the normals drawn from S and P to the respective curves make angles with the base-line, having the relation $\theta'=2\phi'$.

If now we join $N_1P_1$, $N_2P_2$, &c. without making any assumption as to the value of the angles at $P_1$, $P_2$, &c. we have, by the general equation for reflecting surfaces :*

Length of reflected ray $=\frac{1}{2}$ radius of curvature $\times$ cosine of angle of reflexion,

or

$$SP=NS.\cos NSP.$$

Therefore the angle at P is a right angle. and NP is a normal to the caustic. In other words, *the normals drawn to the respective curves from the extremities of the reflected ray intersect in the base.* Also

$$NP=NS.\cos SNP=NS.\cos(\theta'-\phi')=NS\cos\phi',$$

which may be written :

$$\rho'=\rho\cos\phi' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

Now consider ON, the intercept on the base-line made by the normals NS and NP at any point.

If $x=\nu$ be the length of ON, measured from O, and $a$ the radius of the generating circle of the cycloid, we have by the "tangential equation" of the cycloid and trochoid

$$\nu=2a\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

as an equation between coordinates of the reflecting surface (Williamson, Diff. Calc. p. 339).

* In the Memoir by Sir William Hamilton, before referred to, this relation is deduced from the general differential equation of the reflected ray, and is shown to be true for any reflecting surface, where the ray is contained in the plane of the greatest or least osculating circle to the mirror (*Trans. Roy. Irish Acad.* Vol. XV. p. 97).

And in the equation of the caustic we have, for the same values of ON or $\nu$,

$$\theta' = 2\phi' \therefore \nu = a\theta' = 2a'\theta'. \quad \ldots \ldots \ldots \quad (c)$$

The caustic, therefore, satisfies the "tangential equation" for the cycloid and trochoid generated by a circle of radius $a' = 2a$. It must be a cycloid if its normal vanishes at two points on the base-line. At the point O, where the reflecting curve and the caustic are in contact

$$\text{SN or } \rho = 0 : \rho' = 0 \text{ [by Equation } (a)].$$

At the centre of base-line

$$\rho = 2a, \ \phi' = \frac{\pi}{2}, \ \rho' = \rho \cos \phi' = 0.$$

The caustic meets the base in two cusps, one of them being coincident with the cusp of the reflecting curve, and the other being at the middle of the base-line.

The caustic is therefore a cycloid with radius of generating circle:

$$a' = \frac{a}{2} \quad \ldots \ldots \ldots \ldots \quad (d)$$

and base

$$2\pi a' = \tfrac{1}{2} \text{ base of reflecting cycloid} \quad \ldots \ldots \quad (e)$$

The whole caustic surface is generated by the revolution of the caustic section about the axis of symmetry.

In connection with the caustic of oblique pencils we shall have occasion to refer to the simultaneous equations $(a)$ and $(c)$:

$$\rho' = \rho \cos \phi' \quad \nu = 2a'\theta'.$$

*Caustic of Oblique Pencils.*

With similar notation and construction (see the right quadrant of the plate), and denoting by $(\psi)$ the inclination of the obliquely incident rays to the axis of symmetry of the reflector, and by $\Sigma$ the point where the oblique pencil is normal to the surface, we have, as before, from the general equation of reflecting sufaces,

$$\text{SP}' = \text{NS} . \cos \text{NSP}',$$

and from the preceding analysis we have: angle at P, a right angle: NP′, a normal to the caustic, intersecting NS, the normal to the reflecting surface at a point N in the base-line. Now if we imagine a direct ray and an oblique ray, both incident on the reflector at the same point S, so that the construction in figure (1) is superposed on that of figure (2), we see that the normal SN and the point N are common to both systems. We see

also that the reflected rays SP and SP′ (of direct and oblique reflexion) are inclined to each other at the angle $\psi$; also that the normals PN and P′N (of the caustics of direct and oblique reflexion) have the same inclination $=\psi$. Hence for any one point in the base-line,

$$\theta'' = \theta' \mp \psi;$$

and for *any* two points in the base-line, $(x=\nu_1)$ $(x=\nu_2)$ we have, by subtraction,

$$\theta_1'' - \theta_2'' = \theta_1' - \theta_2'; \quad \nu_1' - \nu_2' = \nu_1 - \nu_2;$$

that is, for equal differences of base (or progression of the rolling circle) the differences of deflection of the normals in the two caustics are equal.

The caustic of oblique reflexion is therefore a cycloid satisfying an equation of the form

$$\nu = a''\theta''.$$

It consists of two unequal branches meeting in the focus of the oblique pencil, or rather of two separate cycloids on unequal bases, and together occupying the base of the reflecting cycloid.

Observing that the length of base of the caustic of direct reflexion is

$$\nu = 2\pi a',$$

it is easily seen that for the caustic of oblique reflexion the bases of the two branches are

$$2\pi a'' = 2a'(\pi + \psi) \quad ; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (f)$$

and

$$2\pi a''' = 2a'(\pi - \psi) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (g)$$

by which the generating radii $a''$ and $a'''$ are determined.

It is supposed that in the case of the oblique pencil the whole caustic surface is formed by revolution with varying parameter about the line ΣN, which is thus an interior tangent to the surface. For direct pencils the caustic surface is obviously a true figure of revolution about $S_0P_0$.

The result of a careful investigation of the aberration is that at the circles of least aberration or least confusion there is very little difference between the sphere and the cycloid in the matter of lateral aberration, while if the preceding analysis be well founded there would be little or no longitudinal aberration for the images formed in a cycloidal mirror. The epicycloidal caustic of the circle of curvature falls within the cycloidal caustic in the figure.

The limits of this paper, however, do not admit of the further discussion of this subject.

## *Results.*

The chief interest of the discussion turns on the possibility of obtaining symmetrical images from the caustics of oblique pencils of parallel rays.

1. In every caustic there are two principal points in the curve to be considered. One of these (usually denoted by the letter $q$) is the focus of the elementary pencil reflected from the central point of the mirror. The other principal point is the focus of that particular element of the pencil which is a normal to the reflecting surface (F).

In astronomical instruments, where the celestial arc viewed in the field is of less angular extent than the arc of the mirror, either of the points described is a possible focus. The question which of the two is the true visible focus of the infinitely distant point is one which must be considered separately for each kind of reflecting surface; because, in general, a visible image will only be formed at or near the point where the curvature of the caustic is a maximum, and the point of maximum curvature can only be determined from the equation of the caustic itself.

2. Other conditions being supposed equal, that form of mirror is to be preferred in which the visible image is formed at the point $q$; that is to say, at the focus of the element of the converging pencil which comes from the centre of the mirror.

It is proved in the preceding paper that for a paraboloidal mirror this point constitutes the *vertex* of the cubic radical, which is the caustic. At the vertex $\frac{ds}{dp}$ is a maximum; and a greater number of tangent rays will pass through a small finite arc of the caustic at the vertex than will pass through a consecutive arc of equal length. Near this point is the visible image, and it is a remarkable and apparently unique property of the paraboloid that all its visible images are formed *by the rays proceeding from the central part of the mirror.* Moreover the image point is not a cusp, but only a point of maximum intensity in the luminous surface.

It is possible that there is also a secondary focus at the point F where the oblique pencil is normal to the parabola; but this focus has not been investigated.

3. It has been shown for the case of the PARABOLOID that the locus of the field of view is a sphere touching the paraboloid at the vertex, and whose radius is one-fourth the radius of curvature at that point; and, generally, whatever be the nature of the reflecting surface (provided it is symmetrical about a centre), the sphere here found will be the locus of the focus of rays incident near the centre of the mirror. I am indebted to Professor Cayley for the following proof of this interesting theorem :—

In ANY small mirror for parallel rays inclined to the axis in

the principal plane, the locus of the focus is a circle whose diameter $=\frac{1}{2}$ radius of curvature at vertex. (See Figure *c.*)

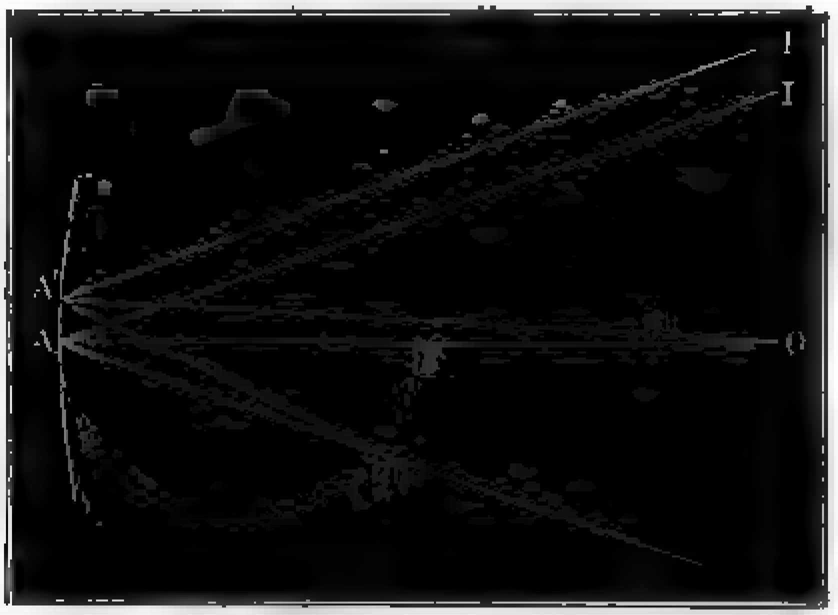



Fig. *c.*

$a$ the radius of curvature O A.

$\alpha$ the inclination I A O.

$\theta$ the small angle A′ O A.

The inclination of A′ $q$ to axis $=\alpha+2\theta$; whence if $x\,y$ are coordinates of A′, and X Y current coordinates,

Equation of

$$
\begin{aligned}
A'q \text{ is } Y-y &= -(X-x)\tan(\alpha+2\theta)\\
Aq \text{ is } Y \quad &= -X\tan\alpha\\
x = a(1-\cos\theta) &= -\tfrac{1}{2}a\theta^2\\
y = a\sin\theta \quad &= a\theta.
\end{aligned}
$$

Equations are

$$Y-y=-(X-x)(\tan\alpha+2\theta\,.\,\sec^2\alpha)$$

say

$$
\begin{aligned}
Y+X\tan\alpha &= a\theta-2X\sec^2\alpha\,.\,\theta\\
Y+X\tan\alpha &= 0
\end{aligned}
$$

whence

$$
\begin{aligned}
a\theta-2X\sec^2\alpha\,.\,\theta=0,\ \text{ i.e. } X &= \tfrac{1}{2}a\cos^2\alpha\ \therefore Y'=-\tfrac{1}{2}a\sin\alpha\cos\alpha\\
X^2+Y^2 &= \tfrac{1}{4}a^2\cos^2\alpha=\tfrac{1}{2}aX,
\end{aligned}
$$

which is circle on diameter A F (if A F$=\frac{1}{2}$ A O).

In the case of the paraboloidal mirror the unsymmetrical form of the visible images near the boundary of the field is attributable mainly to the curvature of the field-surface, which has of course the effect of throwing the non-central part of the field outside the focus of the eye-piece or outside the plane of the

photographic plate, as the case may be. With a photographic plate ground to a *concave* surface of the proper curvature, there is reason to believe that symmetrical star images may be obtained in a field of the usual angular extent. But this is subject to the objection that the plate will always stop out the central and best part of the pencil.

4. In the SPHERICAL MIRROR the visible image will not coincide with the focus for rays incident at the centre of the mirror unless the angle subtended by the arc of the mirror is supposed to be small relatively to the angle of incidence of the oblique pencil. For the actual conditions of astronomical images the visible field will be the locus of the point F, or locus of the epicycloidal cusps, which are the points of greatest condensation for the respective pencils. For any given pencil the cusp of the caustic lies in the line where the ray is a radius of the spherical surface. Hence the geometric field is a spherical surface concentric with the mirror and having half the radius; and the visible field lies very near it.

5. Evidently a spherical mirror will not give symmetrical images, except near the centre, because it is only at the centre of the field that the visible images are formed by the central part of the mirror. Neither will the sphere give a flat field, though it will give a nearer approach to one than the parabola. Against this advantage we must set off the objection that, except at the centre of the field, its images are not formed by the central part of the mirror.

6. As to the CYCLOIDAL MIRROR, if the preceding analysis be correct, the locus of the cusps of the cycloidal caustic is a plane surface, but the images become unsymmetrical as they recede from the centre of the field. It is not meant to be asserted that the visible field will be a true plane, because the visible field is the locus of the circle of least aberration, which is not identical with the locus of the caustic cusps. But the field will be very nearly a plane surface.

It is right to add that the possibility of obtaining a flat field by reflexion has been doubted by mathematicians of high authority, and it must be left to the reader to form his own opinion of the validity of the reasoning by which the conclusion last announced has been reached.

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## *On some Nebulæ hitherto suspected of Variability or Proper Motion.* By J. L. E. Dreyer, Ph.D.

The discrepancies met with in comparing observations of nebulæ by different observers are frequently so great that more or less positive assertions have naturally from time to time been made as to variability or changes in the objects. While many of these assertions can at once be dismissed as showing that too

little regard has been paid to the great difficulties attending observations of nebulæ or to the vast influence of the state of our atmosphere from night to night, others are either founded on undoubted facts or appear at least to others than practised observers of nebulæ to be so. It seems that the only well authenticated cases of change in nebulæ are changes of brightness only, while we *so far* do not possess any clear evidence of change of form or change of place.

The most generally known case of a nebula having disappeared—that of Hind's nebula in *Taurus*—is also the most certain and undisputed one. Chacornac's nebula (G.C. 1191), though only seen by that observer, doubtless also existed in a place where no nebulosity has since been seen; but these two cases are the only ones which are quite certain. It is true that some of William Herschel's nebulæ cannot now be found, but these may either have been comets, or, more probably, some error of observation has vitiated the position he gives for the object in question. The latter case must, *e.g.*, have occurred on April 2, 1801, when he compared a number of nebulæ (among which are three of the first class) with one comparison star, which he identifies as "208 (N) *Camelop.* of Bode's Cat." As not one of these objects can now be found, it is evident that he made a mistake either in identifying the star or in making or recording the observation of it. Another case is G.C. 2179 = I 26, which possibly may be an erroneous observation of the neighbouring M 95. The remarkable nebula at Merope, and a less notable one, G.C. 710, were by d'Arrest and others supposed to be variable, because the difficulty of seeing them with a large aperture made it appear strange that they had been described as conspicuous in small instruments. This difficulty is, however, now universally understood to arise from the use of too high a power with consequent smallness of field; and nobody now suspects these two nebulæ of variability.

I shall not enter into an examination of the numerous instances where observers disagree as to the brightness of an object. Probably atmospheric or instrumental circumstances could in most cases account for this disagreement; but, all the same, the possibility of nebulæ changing in lustre cannot be denied, since we have witnessed the total disappearance of two of them. But I propose to go through all the objects which have been suspected of having changed in form or position, and I trust I shall be able to prove that not one of the cases can be considered as well established.

Most of the nebulæ examined in the following are double nebulæ, which have been suspected of being in motion. They have been collected (from d'Arrest's work) by M. Flammarion in an appendix to his "Catalogue des Étoiles doubles et multiples en mouvement relatif certain." In all cases the suspicion is founded on differences in their relative positions, as recorded by Sir William and Sir John Herschel and by later

observers, and it does not seem to have been generally noticed that Sir W. Herschel never employed a micrometer, but merely *estimated* the position-angles and distances of neighbouring nebulæ, and that Sir John Herschel did the same from the commencement of his observations, and up to July 5, 1828.* After this date the eye-piece of his 18-inch Reflector was furnished with a wire micrometer, with which, however, only position-angles could be measured, while, as formerly, distances (both of nebulæ and double stars) were only estimated. Even then he frequently estimated angles, in which case they were given only to whole degrees; whenever a decimal is given it shows that the position-angle was measured. Although such estimations should evidently not be used (or at least only with great caution) in drawing conclusions as to orbital or proper motion, I have thought it desirable to re-observe many of the objects with the new 10-inch Refractor at the Armagh Observatory, which I am devoting to micrometric observations of nebulæ. The pair h 444–445 were measured with a filar micrometer; the others with a small micrometer with steel bars instead of spider lines, and requiring no illumination. Although distances measured with the latter kind of micrometer are doubtless subject to systematic errors (which I intend to investigate), their accuracy is quite sufficient for the present purpose.

*Great Nebula in Andromeda.*—The question as to variability of this object, first raised by Le Gentil, has been thoroughly discussed by G. P. Bond in his well-known Memoir, and he comes to the conclusion that the views of Le Gentil are "far from being supported by an amount of evidence adequate to such a conclusion." The nucleus has been drawn or described in a remarkably different manner; by some (*e.g.* Schultz, Schönfeld, Vogel) as starlike, by others at the very same time (*e.g.* Schmidt: see Vogel's note in *Astr. Nachr.* No. 2681) as a very soft and gradual condensation. These strange discrepancies are, however, explained by the valuable experiments made by Dr. Copeland † with different eyepieces, which show what an immense influence the magnifying power has on the appearance of the nucleus, the lower powers making it more starlike, the higher ones more soft-looking and extensive. Whether the new star of 1885 really belonged to the nebula or not does not concern us here; but Dr. Copeland's experiments with artificial stars and different illumination of the field prove that, even if a real change had taken place in the nebula at the time of the outburst, it could not have been detected as long as the star was shining brightly. Since the fading of the star the nebula has quite resumed its former appearance.

III. 228–229 = *h* 251–252.—M. Flammarion remarks that W. Herschel estimates the distance at about 1′, while d'Arrest gives

* See *Mem. R.A.S.*, vol. iv. p. 331.

† *Monthly Notices*, vol. xlvii. p. 60.

$\Delta\alpha = 8^s$, and estimated (on one occasion) the distance $= 112'' \pm$. There is, however, perfect accordance between J. Herschel and d'Arrest, for the former gives $\Delta\alpha = 7^s{\cdot}5$, while the distance resulting from his positions is $134''$. Both nebulæ are very faint, especially the following one, which d'Arrest describes as "indubitatum nebulæ vestigium, adeo tenue tamen, ut visum ægre sustineat." His estimated distance is too small, as one can see by a glance at his $\Delta\alpha$.

III. 574–575 = *h* 294–295.—While Sir W. Herschel does not say anything about the relative positions of these two very faint objects, Sir John gives the following positions for 1830 (one observation):—

| | h | m | s | ° | ″ | |
|---|---|---|---|---|---|---|
| *h* 294 | 3 | 10 | 25·8 | 49 | 18·22 | The *np* of 2. Pos. from the following, which is the largest, 352°·4, dist. 100′. |
| 295 | 3 | 10 | 26·9 | 49 | 16·44. | The *nf* of two. |

while according to d'Arrest $\Delta\alpha = 4^s$, the following one being $124''$ *south* of the preceding one. A glance at Sir J. Herschel's positions and remarks shows that no conclusion can be drawn from them. If the first one was "the *np* of 2," the second cannot have been "the *nf* of 2," and if the position-angle of the first one from the second one was 352°·4, the N.P.D. of the first one must have been smaller than that of the second, and not greater. D'Arrest's $\Delta\alpha$ and $\Delta\delta$ give the position-angle of the first one = 339°·9 and the distance = $132''$; but he remarks: "Situs relativi observatio plurimis laborat difficultatibus," so that the difference of 12° between Herschel and d'Arrest is not surprising. Probably Sir John Herschel determined the R.A. and Decl. of the following one, measured the position-angle, estimated the distance, and afterwards from these data made out the $\Delta\alpha$ and $\Delta\delta$, in doing which he accidentally gave the latter the wrong sign, placing the preceding nebula south of the following one, instead of north of it.

II. 8–9 = *h* 316–317.—M. Flammarion says that in 1830 (should be 1827) the position-angle was 30° to 40°; while d'Arrest in 1862 (should be 1863–65) found it = 80° ±. This is however not correct, for Herschel says: "Pos. by a drawing made at the time 30° . . . 40° *nf*," which means that he estimated it equal to 60° . . . 50°. At Birr Castle the angle was in 1850 on two nights measured = 77° and 75°·5, and in 1876 = 78°·8. In 1783 Sir W. Herschel determined the places of these two nebulæ, according to which the second one should then have been 1′ *south* of the first one; but as his earliest observations are very inaccurate, no conclusion can be drawn from them. At any rate, the objects were stationary from 1850 to 1876.

*Great Nebula in Orion.*—This object has more frequently than any other nebula been suspected of having varied in form, but on the other hand it has been more thoroughly examined and discussed than any other. From his own observations and his

examination of the principal monographs, d'Arrest drew the conclusion that "the observed changes in this vast mass of gas seem exclusively to turn out to be temporary fluctuations of brightness,"* and the elaborate discussion of all previous observations in connection with his own led Professor Holden to state "that the figure of the nebula in *Orion* has remained the same from 1758 till now (if we except a change in its apex about 1770, which appears quite possible), but that in the brightness of its parts undoubted variations have taken place, and that such changes are even now going on."†

IV. 25 = *h* 428.—A double star, *h* 749, involved in (or projected on) a fan-shaped nebula. In 1827 the position-angle was estimated = 125°, and the distance 12″; in 1863 d'Arrest estimated them 120° and 4″. There has been no change, as two observations made at Birr Castle in 1874–76 give 119° 11″. But even if there had been a change in the distance of the double star, this could not really be called a change in a nebula. Sir W. Herschel did not notice the duplicity of the star.

II. 316–317 = *h* 444–445.—In the *Astr. Nachr.* No. 1366, d'Arrest called attention to the following remarkable discrepancy between the then existing observation of this fine double nebula:—

| | | | | | |
|---|---|---|---|---|---|
| H | 1785 | Pos. | —° | Dist. | 60″ |
| *h* | 1827 | „ | 45 | „ | 45 |
| d'A | 1862 | „ | 56·5 | „ | 28·5 |

At first sight this certainly looks like orbital motion. But, unfortunately, Sir John Herschel only estimated the angle and distance, and his two estimates of the latter differ very much *inter se*, being 30″ and 60″. It is, however, only fair to add that d'Arrest merely showed the disagreement without making it out to be a sure case of motion. The following later measures show that the pair have been at rest during the last twenty-five years:—

| | | | | | |
|---|---|---|---|---|---|
| Schultz | 1864-65 | Pos. | 59°·1 | Dist. | 31″·6 (4 nights). |
| Dreyer | 1876 | „ | 53·9 | „ | 27·7 (Birr Castle, 1 night). |
| Dreyer | 1887 | „ | 57·3 | „ | 32·3 (2 nights). |

The two nebulæ are connected (see *Phil. Trans.* 1850, pl. xxxviii., and *Birr Obs.* 1848–78, pl. ii.). The following one is fainter, smaller, and far less condensed in the middle than the preceding one.

*h* 705.—This is a very interesting object: a double star (*h* 2529) with nebulosity attached. In "The Observatory," vol. viii., p. 127, Mr. H. Sadler suggested that here might be a possible case of proper motion in a nebula, since Mr. Burnham

* *Undersögelser over de nebulose Stjerner* (1872), p. 42.

† Holden's *Monograph*, p. 225.

in 1879–82 saw the nebula "19″ from the principal star," while Sir J. Herschel in 1830–31 said the nebula was about the principal star. It will be well to put together all the observations made by Herschel, both as they are recorded in his fifth list of double stars * and in the *Phil. Trans.* 1833.

| Sweep. | Pos. | Dist. | Double Star Obs. | Obs. of Neb. |
|---|---|---|---|---|
| 243 | Pos. 95°·3 | Dist. 1½″ | A most curious, delicate, and interesting object. The nucleus of a very faint nebula examined with 320, proves to be distinctly a first-class double star. | A very close D * of the first class involved in a nebulous wisp. "A most curious, delicate, and interesting object." |
| | ,, 10·8 | ,, 7 | | |
| 242 | ,, 95·4 | ,, 1 | A nebula strongly suspected about the close double star and a fourth star also suspected. | A triple star in a nebula, a fourth * suspected. |
| | ,, 8·0 | ,, 7 | | |
| | ,, 330±† | ,, 6 | | |
| 338 | ,, 7·0 | ,, 18 | A double star in a very faint nebula (a hurried observation). | A double * in a *v* F nebula. |

In the "Remarks" on the double-star observations (*l.c.* p. 78) Herschel alludes to this object, saying that "a minute and very close double star forms the nucleus of a small round nebula; one or two other small stars in the immediate vicinity seem unconnected with it, but the exactly central position of the double star strongly points to a physical relation between them." It is, however, not to these remarks, written several years afterwards, but to the observations themselves that we must look for evidence of motion. D'Arrest observed the object three times in 1864-65; he saw a star of 10·11 magnitude with a star 13 mag. about 12″ *nnf.*, the latter being the centre of a nebula which reached to the former star. In 1872 the following observation was made at Birr Castle: "Neb. to * 9m Pos. 193°·0, Dist. 19″·7, * 9 to * 12m 243°·3, 8″·8," and in 1876: "Double star, 10·11 and 15·16 mag. 5°·0, 21″, *v* F *neby* round it, E north and south." Mr. Burnham ‡ in 1879 and 1882 saw only the wide pair in Pos. 7°·9, Dist. 19″·0 (and once the faint companion *sp* the brighter star), and remarks, "The nebula is now 19″ from the principal star."

All this does not seem to prove that the nebula has moved away from the close double star, for it is only in the *remarks* that Herschel calls the latter the nucleus of the nebula, while the observation in sweep 243 merely says that it was involved, which is not contradicted by the later observers. Mr. Burnham of

* *Mem. R.A.S.*, vi. p. 32.
† Should be 230°. See d'Arrest and Burnham.
‡ *Mem. R.A.S.* xlvii. p. 270.

course did not mean that the *edge* of the nebula was 19″ from the close double, but that the nucleus was at that distance, which it is still. Having during the two years elapsed since Mr. Sadler's note appeared quite forgotten all the details about this object, I looked it up on March 15 last on finding it on my working list, and noted :—

"Nebulosity nearly reaches the south * if it does not actually touch it. It is oval in shape, E in the same pos. angle as the two stars. I saw only the two stars, but definition was not particularly good. The north star looks more like a nucleus than a *."

This agrees perfectly with d'Arrest's observations, so that there can have been no "proper motion" between 1865 and 1887, and it may safely be inferred that there has been none since 1830, unless we are to believe in this and similar cases that nebulæ in the good old days moved about as they liked, but have been on their good behaviour since 1861 and kept quiet.

*Great Nebula around η Argûs.*—It is sufficient to refer to the various papers on the alleged discovery of vast changes in this nebula in the *Monthly Notices*, vol. xxxi. There has ever since been perfect unanimity among astronomers that the changes were "altogether imaginary" (*Ibid.* xxxii. p. 178).

I. 248, II. 832 = *h* 983–984.—W. Herschel in 1790 made $\Delta\alpha = 12^s$, giving both nebulæ same N.P.D. In 1832 J. Herschel found $\Delta\alpha = 12^s$, the second nebula being (estimated) 45″ north of the first. In 1866 d'Arrest found $13^s\cdot5$ and 57″. "Mouvement certain," says M. Flammarion. On the 27th April last I found Pos. angle = 61°·1, Dist. = 120″·0, or $\Delta\alpha = 14^s\cdot0$, $\Delta\delta = 58''$. Both are pretty large and *vgb* M to a very soft-looking nucleus. No change.

III. 394–395 = *h* 1065–1067.—M. Flammarion considers that the position-angle has changed 20° since Sir J. Herschel in 1830 twice estimated it = 70°; while d'Arrest in 1864 on three occasions states that they are on the same parallel. But in 1865 he says that the second one is "pauxillum quid ad boream," and so it is, for at Birr Castle in 1872 it was measured in Pos. 82°·7, Dist. 69″·5, and on April 11 last I found Pos. 79°·5, Dist. 68″·5.

II. 751–752 = *h* 1905.—Two connected nebulæ, the preceding one very little elongated, the following one much so; figured in *Phil. Trans.* 1833, fig. 77 (one observation) and 1861, fig. 31. The late Lord Rosse remarked (*l.c.* p. 704) that in Herschel's drawing the axes of the two nebulæ are in a line; in 1850 Mr. G. Johnstone Stoney found them not to be in a line; in 1855 Mr. Mitchell (at Birr Castle) remarked that the axes were not in a line but were parallel; while in 1861 (when the drawing in P.T. 1861 was made) they were neither in a line nor parallel, but inclined at an angle of 16°. Since then the following observations have been made:—

Birr Castle, 1871. No E of *p* neb noticed, the axis of the *f* neb makes an angle of about 12° by a diagram.

Birr Castle, 1872. The *f* one E 130°·4 (2 meas.). Pos. of line joining centres 117°·6 (2). The E neb [*f* one] slightly cometic.

Armagh, 1887, April 27. *p* one vvl E, apparently towards *f* one, the latter very diffused and hazy, Pos. of E 128°·4 (2 meas.), therefore difficult to measure; line joining them 120°·2 (2 meas.).

The very hazy look of the two nebulæ, the small amount of elongation of the first one, and the want of sharp condensation in both of them are more than sufficient to account for the disagreement between the various observers.

M 20=V 10, 11, 12=*h* 1991, 3718, the "trifid nebula." This forms the subject of an elaborate monograph by Professor Holden,* in which it is attempted to prove that from 1784 to 1833 the triple star was centrally situated between the three nebulosities, but that from 1839 to 1877 it was involved in the south following mass of nebulosity. The latter proposition rests on a firm basis, as the nebula has been repeatedly examined and drawn with every care since 1839; but this cannot be said about the first proposition. At the Cape of Good Hope, Sir J. Herschel made a drawing in a single night (August 1835), which exhibits the triple star on the very edge of the *sf* nebulosity. A careful drawing made at Slough was lost, and that engraved in P.T. 1883, fig. 80 (which shows the triple star in the midst of a vacuity) was constructed from sketches "the rudest imaginable aided by memory." The other evidence as to the position of the star between 1784 to 1833 consists in various notes by Sir William and Sir John Herschel. But the former never says that the double star was *in the middle of the vacuity*, but in 1784 he describes the object as "three nebulæ faintly joined form a triangle; in the middle is a double star," and in 1786: "a double star with extensive nebulosity of different intensity; about the double star is a black opening." It is quite true that Sir John Herschel on three occasions† states that the star is in the middle of the vacuity. But is it so strange that at an altitude of only 15°, and during the strong twilight of our summer months (sweep 30 was made on July 1, 1826), the nebulosity could not be traced close to a bright double star of the 8·5 and 9th magnitude? It is at any rate curious that the critical time when the alleged motion of the nebula towards the star should have taken place is precisely the moment when we exchange strong twilight, very low altitude, rude sketches for little or no twilight, much higher altitude, and careful drawings.

The drawings made by Mason, Lassell, and Trouvelot differ in many details just as the various drawings of *Orion* do; and very possibly changes of brightness have taken place, both near

* *Am. Journ.* xiv. Dec. 1877.

† *Mem. R.A.S.* ii. p. 490, in a footnote to a paper on the *Orion* nebula, *ibid.* iii. p. 63, in his observations of double stars, and in sweep 30, *Phil. Tr.* 1833, p. 460.

the double star and in the other part of the nebula; but that the nebula should about 1835 in the course of a few years have *moved* so as to envelop the star, after which no sensible change occurred again so far as published observations go, does not seem sufficiently well proved.

M 17=*h* 2008, *Omega* nebula.—In the *American Journal*, vol. xi., May 1876, Professor Holden published a paper "On Supposed Changes in the Nebula *M* 17," in which he endeavours to show by a comparison of his own observations (made with the Washington 26-inch refractor) with those of J. Herschel, Lamont, Lassell and Trouvelot that the western branch of the Ω has moved relatively to the little group of stars 10, 3, 11 (Lassell) at the *np* end, and particularly with regard to the star No 1 at the *sp* side of the Ω.* The nebulosity is very diffused at the group of stars, yet there is very little difference between the various drawings, but the star 1, on which reliance is chiefly placed, was by J. Herschel in 1837, and Lassell in 1862, found to be on the inner (concave, north following) edge of the curve of the nebula; while Holden and Trouvelot in 1875 placed it well within the nebulosity, in fact preceding nine-tenths of it. A drawing by Le Sueur made in 1869 (*Proc. R. S.* vol. xviii., overlooked by Professor Holden) agrees with the one made at Washington, so that the change should have taken place between 1862 and 1869. But a drawing made by M. Tempel in 1876 with the 11-inch refractor at Arcetri † agrees with the *earlier* drawings in this particular, while two sketches made at Birr Castle in 1854 ‡ agree with the *later* drawings. There has therefore certainly not been any bodily shifting of the nebula, but the possibility of changes of brightness are not excluded.

II. 426–427=*h* 2087–2089.—M. Flammarion remarks that there is a great disagreement between J. Herschel's and d'Arrest's difference of declination, the former observer making $\Delta\delta=82''$, the latter $61''$. It should have been stated that it was only on one night that d'Arrest found $\Delta\delta=59''$ to $63''$, for the mean results of his three nights give $81''$. In 1876 I found at Birr Castle $78''.4$ (one measure of pos. and distance).

III. 210–211=*h* 2202–2203.—M. Flammarion repeats a remark of d'Arrest's that J. Herschel in 1828 found $\Delta\alpha=10^s.0$ (should be $9^s.0$) and $\Delta\delta=37''$, while d'Arrest found $10^s.5$ and $53''$. But the mean of d'Arrest's results gives $8^s.2$ and $62''$. This faint pair, between which d'Arrest found a *v* F, *v* S nebula (G.C. 6112), and of which the elongation of the preceding one makes the measurement of $\Delta\delta$ difficult, has been frequently observed of late years, showing no appreciable change.

* See Mr. Lassell's drawing (fig. 32) and skeleton chart (fig. 32 A) in *Mem. R.A.S.* vol. xxxvi.

† See Winnecke's review in *Vierteljahrsschrift d. a. G.* xii. p. 245.

‡ *Observations of Nebulæ*, 1848–78, pl. vi.

| | | | | |
|---|---|---|---|---|
| D'Arrest | 1861-64 | $\Delta\alpha = 8^s\!\cdot\!2$ | $\Delta\delta = 62''$ | 3 nights. |
| Schönfeld | 1861 | 9·72 | 59·5 | 5 " |
| Schultz | 1863-65 | 9·05 | 61·0 | 3 " |
| Schönfeld | 1864 | 9·38 | 71·3 | 1 night. |
| Vogel | 1869 | 9·38 | 69·0 | 2 nights. |
| Dreyer | 1877 | 8·92 | 60·7* | 1 night. |
| Dreyer | 1885 | 8·86 | 66·0 | 1 " |

III. 855–856 = *h* 2294–2295.—These also occur in M. Flammarion's list, because W. Herschel in 1790 *estimated* the position-angle = 60° and the distance 60″, while d'Arrest found 50° and 43″. The objects are both excessively faint, and it would be easy to count up hundreds of similar discrepancies. In 1872 the angle and distance were measured at Birr Castle, and found = 51°·0 and 61″·5.

I have spared no trouble in going through these cases one by one, although in some the evidence was of such a character as hardly to deserve a refutation. I would suggest to anybody who in future should feel inclined to lay a case of proper motion or variability of a nebula before the public, first to peruse the remarks of d'Arrest in the *Astr. Nachr.* vol. lvii. col. 342. In making micrometric observations of these interesting objects we must be content to work for unborn generations, or at least not to expect immediate and startling results, which would look well in popular books.

*Armagh Observatory:*
1887, *May.*

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## *Note on the Effect of Refraction in Stellar Photography.*
By J. L. E. Dreyer, Ph.D.

In his paper read at the April meeting of the Society, Mr. Grubb has assumed that a displacement of 0″·5 is the smallest which would sensibly affect the symmetry of the image of a star on a photographic plate. It is of interest to see how soon refraction will move the image to this extent, assuming the action of the clock to be absolutely perfect and the instrument accurately adjusted.†

The well known expressions for refraction in Right Ascension and Declination, first given by Bessel in the *Monatliche Correspondenz*, xvii. p. 214, are

$$57''\frac{\tan t \sin \psi}{\cos\delta \sin(\psi+\delta)} \text{ and } 57'' \cot(\psi+\delta)$$

* In the single measure of distance at Birr Castle on Oct. 29, 1877, there is an obvious error of one revolution of the screw = 65″·1.

† This question is not considered in Prof. Pickering's valuable paper, "Investigation in Stellar Photography."

where $\psi$ is determined by $\tan\psi = \cos t \cot\phi$, while $t$ is the hour-angle, $\delta$ the Declination, and $\phi$ the latitude. The rate of change of refraction is found by differentiation with regard to $t$.

$$\frac{d\alpha}{dt} = 57''\left(\frac{\cos\psi}{\sin(\psi+\delta)\tan\phi}\right)^2 (1 + \tan\phi\tan\delta\cos t)$$

$$\frac{d\delta}{dt} = 57''\left(\frac{\cos\psi}{\sin(\psi+\delta)}\right)^2 \cot\phi\sin t$$

The trail left on the plate after an exposure of $n$ seconds of time will now be the resultant of the displacements along the parallel and the hour-circle equal to

$$\frac{15n}{206265}\frac{d\alpha}{dt}\cos\delta \quad\text{and}\quad \frac{15n}{206265}\frac{d\delta}{dt}$$

Assuming the latitude = 50°, the following table shows the values of these quantities for various parts of the sky for a change of $4^m$, or 1° in hour-angle.

| $t =$ | $0^h$ | | $1^h$ | | $2^h$ | | $3^h$ | | $4^h$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $d\alpha\cos\delta$ | $d\delta$ | $d\alpha\cos\delta$ | $d\delta$ | $d\alpha\cos\delta$ | $d\delta$ | $d\alpha\cos\delta$ | $d\delta$ | $d\alpha\cos\delta$ | $d\delta$ |
| $\delta =$ 0° | 0″·99 | 0″·00 | 1″·07 | 0″·33 | 1″·33 | 0″·79 | 1″·99 | 1″·68 | 3″·98 | 4″·10 |
| +25° | 0·71 | 0·00 | 0·73 | 0·16 | 0·81 | 0·36 | 0·96 | 0·64 | 1·26 | 1·12 |
| +50 | 0·64 | 0·00 | 0·64 | 0·13 | 0·66 | 0·28 | 0·69 | 0·45 | 0·72 | 0·67 |
| +75° | 0·71 | 0·00 | 0·70 | 0·16 | 0·66 | 0·31 | 0·60 | 0·47 | 0·51 | 0·63 |

The value of $d\alpha\cos\delta$ increases with south declination, being on the meridian and at $-10° = 1''·28$, and at $-20° = 1''·87$. Refraction accelerates the rising of a star, so that the apparent place of a star in the east will be in advance of the true one, but the difference of hour-angle gradually diminishes as we approach the meridian. After the culmination they change places, the apparent place now being behind the true one. A slight uniform retardation of the clock will thus do away with the greater part of the error in the direction of the parallel, as the table shows how very slowly $d\alpha\cos\delta$ changes with the hour-angle. The case is different with regard to the effect of refraction along the hour-circle, as the full amount of the change in this will cause displacement of the star on the plate, and it seems that a declination clock will ultimately become desirable, though the mechanical arrangements would be somewhat complicated if the instrument were to be available for lengthened exposures on any part of the sky. But this would be unnecessary in the case of systematic work, such as star-charting, as this could always be carried on close to the meridian, where the refraction in declination changes very slowly. Thus, for the latitude of 50° an equatoreal star will be $27^m$ past the meridian, and a star of +25° Declination $39^m$ past the meridian, before a displacement of $0''·5$ occurs.

## *The Right Ascensions of certain Stars within Ten Degrees of the Pole. Reduced from Observations by F. G. W. Struve.*
By Henry Lefavour.

*(Communicated by Prof. T. H. Safford.)*

The observations from which the following star-places have been determined were made by Struve, at Dorpat in 1818 and 1819, and are published in the second volume of his "Dorpat Observations." The list includes all the stars that he observed which lie within ten degrees of the pole, with the exception of *Polaris*, the observations of which have already been reduced, and the stars which he designated as *Anonyma*, most of which are unimportant, and were observed but once, or at the most two or three times. The Right Ascensions are reduced to 1820·0, but no proper motions have been applied, and the epoch is consequently given for each star.

*Catalogue of Mean Right Ascensions for* 1820·0.

| No. | Struve's Name. | Gr. No. | Misc. Cat. and No. | No. of Obs. | Mean Right Ascension for 1820·0. h | m | s | Epoch. |
|---|---|---|---|---|---|---|---|---|
| 1 | Cephei 320 | 67 | ... | 3 | 0 | 19 | 46·097 | 1818·9 |
| 2 | Ursæ Minoris 1 | 144 | Bradley 65 | 9 | 0 | 39 | 10·712 | 1819·0 |
| 3 | *a* Cephei 321 | 177 | ... | 1 | 0 | 45 | 53·920 | 1818·9 |
| 4 | Cephei 322 | 195 | Bradley 95 | 1 | 0 | 48 | 21·260 | 1818·9 |
| 6 | Rangiferi 15 | 424 | ... | 3 | 1 | 47 | 55·007 | 1818·8 |
| 7 | Rangiferi 16 | 426 | ... | 2 | 1 | 48 | 33·430 | 1818·8 |
| 8 | Rangiferi 21 | 505 | ... | 1 | 2 | 12 | 33·640 | 1818·8 |
| 9 | Rangiferi 23 | 527 | ... | 2 | 2 | 22 | 35·215 | 1818·8 |
| 10 | Rangiferi 26 | 580 | Bradley 395 | 3 | 2 | 44 | 34·127 | 1818·9 |
| 11 | Rangiferi 29 | 595 | Bradley 402 | 2 | 2 | 51 | 33·490 | 1818·8 |
| 12 | Rangiferi 323 | 642 | ... | 4 | 3 | 8 | 58·663 | 1818·9 |

| No. | Struve's Name. | Gr. No. | Misc. Cat. and No. | No. of Obs. | Mean Right Ascension for 1820·0. h | m | s | Epoch. |
|---|---|---|---|---|---|---|---|---|
| 13 | Rangiferi 43 | 779 | ... | 1 | 3 | 56 | 15·090 | 1818·9 |
| 14 | Camelopardalis 36 | 856 | Cephei 50 H. | 1 | 4 | 37 | 7·100 | 1818·9 |
| 15 | Camelopardalis 64 | 944 | .. | 1 | 5 | 5 | 21·020 | 1819·5 |
| 16 | Ursæ Minoris 4 | 1119 | ... | 3 | 6 | 15 | 36·070 | 1819·1 |
| 17 | Camelopardalis 120 | 1141 | Cephei 51 H. | 48 | 6 | 13 | 6·274 | 1818·9 |
| 18 | Camelopardalis 131 | 1255 | ... | 7 | 6 | 50 | 46·230 | 1818·8 |
| 19 | Camelopardalis 132 | 1259 | Camelopardalis 25 H. | 3 | 6 | 54 | 38·480 | 1818·8 |
| 20 | Camelopardalis 136 | 1278 | ... | 6 | 7 | 1 | 24·485 | 1818·8 |
| 21 | Camelopardalis 150 | 1339 | Camelopardalis 28 H. | 6 | 7 | 26 | 1·997 | 1818·8 |
| 22 | Camelopardalis 152 | 1355 | ... | 2 | 7 | 29 | 49·080 | 1818·8 |
| 23 | Camelopardalis 156 | 1359 | ... | 4 | 7 | 32 | 25·645 | 1818·8 |
| 24 | Camelopardalis 170 | 1391 | ... | 4 | 7 | 48 | 43·455 | 1818·8 |
| 25 | Camelopardalis 180 | 1431 | ... | 5 | 8 | 12 | 49·256 | 1818·8 |
| 26 | Camelopardalis 182 | 1452 | ... | 1 | 8 | 23 | 59·970 | 1818·9 |
| 27 | Camelopardalis 183 | 1463 | ... | 4 | 8 | 28 | 25·360 | 1818·9 |
| 28 | Camelopardalis 184 | 1480 | ... | 1 | 8 | 42 | 35·630 | 1818·9 |
| 29 | Camelopardalis 186 | 1537 | Draconis 1 H. | 16 | 9 | 10 | 32·356 | 1818·9 |
| 30 | Camelopardalis 189 | 1620 | Camelopardalis 29 H. | 4 | 10 | 1 | 44·428 | 1818·9 |
| 31 | Camelopardalis 190 | 1633 | Camelopardalis 30 H. | 1 | 10 | 8 | 7·080 | 1818·9 |
| 32 | Camelopardalis 191 | 1643 | Bradley 1439 | 4 | 10 | 16 | 50·040 | 1818·9 |

| No. | Struve's Name. | Gr. No. | Misc. Cat. and No. | No. of Obs. | Mean Right Ascension for 1820·0. h | m | s | Epoch. |
|---|---|---|---|---|---|---|---|---|
| 33 | Camelopardalis 201 | 1778 | ... | 2 | 11 | 16 | 46·300 | 1818·9 |
| 34 | Camelopardalis 202 | 1782 | ... | 3 | 11 | 18 | 42·923 | 1818·8 |
| 35 | Camelopardalis 204 | 1845 | ... | 2 | 11 | 50 | 39·380 | 1818·9 |
| 36 | Camelopardalis 205 | 1850 | ... | 3 | 11 | 55 | 27·077 | 1818·8 |
| 37 | Camelopardalis 207 (pr.) | 1858 | Bradley 3241 | 4 | 12 | 2 | 41·960 | 1819·0 |
| 37 *a* | Camelopardalis 207 (sq.) | — | ... | 4 | 12 | 3 | 14·118 | 1819·0 |
| 38 | Ursæ Minoris 5 | 1871 | Bradley 1656 | 11 | 12 | 11 | 27·935 | 1818·9 |
| 39 | Ursæ Minoris 6 | 1884 | Bradley 1672 | 14 | 12 | 14 | 37·410 | 1818·9 |
| 40 | Camelopardalis 209 | 1889 | ... | 2 | 12 | 16 | 48·040 | 1818·9 |
| 42 | Camelopardalis 211 | 1927 | ... | 1 | 12 | 39 | 41·950 | 1818·9 |
| 43 | *o* Camelopardalis 212 | 1940 | Camelopardalis 32 H. | 14 | 12 | 47 | 50·664 | 1819·0 |
| 44 | Camelopardalis 213 | 1977 | ... | 3 | 13 | 10 | 57·530 | 1818·9 |
| 45 | Ursæ Minoris 12 | 2006 | ... | 19 | 13 | 20 | 13·481 | 1819·0 |
| 46 | Camelopardalis 214 | 2007 | ... | 3 | 13 | 22 | 29·927 | 1818·8 |
| 47 | Camelopardalis 216 | 2037 | ... | 2 | 13 | 36 | 44·900 | 1818·8 |
| 48 | Camelopardalis 219 | 2063 | ... | 1 | 13 | 48 | 0·920 | 1818·9 |
| 49 | Ursæ Minoris 20 | 2099 | ... | 2 | 14 | 10 | 13·200 | 1818·9 |
| 50 | Camelopardalis 223 | 2196 | ... | 4 | 15 | 3 | 13·838 | 1818·9 |
| 51 | Ursæ Minoris 45 | 2210 | ... | 4 | 15 | 6 | 8·235 | 1818·9 |
| 52 | Ursæ Minoris 44 | 2213 | ... | 1 | 15 | 10 | 59·360 | 1818·9 |

| No. | Struve's Name. | Gr. No. | Misc. Cat. and No. | No. of Obs. | Mean Right Ascension for 1820·0. h | m | s | Epoch. |
|---|---|---|---|---|---|---|---|---|
| 53 | 1 π Ursæ Minoris (pr.) | 2275 | ... | 2 | 15 | 40 | 3·985 | 1819·4 |
| 53a | 1 π Ursæ Minoris (sq.) | 2276 | ... | | 15 | 40 | 16·765 | 1819·4 |
| 54 | ε Ursæ Minoris | 2122 | ... | 70 | 17 | 4 | 46·175 | 1819·4 |
| 55 | Cephei 4 | 2456 | ... | 1 | 17 | 33 | 22·220 | 1818·8 |
| 56 | Ursæ Minoris 79 | 2476 | ... | 1 | 17 | 42 | 55·460 | 1819·0 |
| 57 | δ Ursæ Minoris | 2628 | ... | 72 | 18 | 30 | 18·808 | 1819·3 |
| 58 | 24 Ursæ Minoris | 2667 | ... | 14 | 18 | 37 | 9·626 | 1818·8 |
| 59 | prec. 75 Draconis | 3258 | Bradley 2701 | 2 | 20 | 37 | 45·315 | 1818·9 |
| 60 | 75 Draconis | 3276 | ... | 4 | 20 | 39 | 4·498 | 1818·9 |
| 61 | 74 Draconis | 3277 | ... | 2 | 20 | 39 | 26·350 | 1818·9 |
| 62 | λ Ursæ Minoris | 3308 | ... | 14 | 20 | 37 | 26·841 | 1818·9 |
| 63 | 76 Draconis | 3370 | ... | 8 | 20 | 55 | 0·091 | 1818·9 |
| 64 | Ursæ Minoris 86 | 3548 | ... | 14 | 21 | 33 | 18·064 | 1818·9 |
| 65 | Cephei 180 prec. | 3707 | ... | 4 | 22 | 4 | 10·338 | 1818·9 |
| 65 | Cephei 180 *a* seq. | 3709 | ... | 4 | 22 | 4 | 16·853 | 1818·9 |
| 67 | Cephei 221 prec. | 3820 | Cephei 32 H. | 1 | 22 | 26 | 10·480 | 1818·8 |
| 68 | Cephei 221 *a* seq. | 3824 | Bradley 2997 | 1 | 22 | 26 | 48·360 | 1818·8 |
| 69 | Cephei 233 | 3887 | ... | 3 | 22 | 38 | 50·627 | 1818·8 |
| 70 | Cephei 246 | 3928 | Cephei 34 H. | 1 | 22 | 47 | 54·780 | 1818·9 |
| 71 | Cephei 253 | 3970 | Cephei 36 H. | 2 | 22 | 55 | 27·620 | 1818·8 |

*Williams College, Williamstown, Mass.:*
1837, *May* 3.

## *On the Probable Errors of Transit-observing.*
## By W. H. Finlay, M.A.

In the winter months consecutive transits above and below pole of several stars are often secured on the same night, and a question arises as to how the separate results for azimuthal error are to be combined to form the "adopted" azimuthal error. To settle this question we require to know the probable errors of observation at different declinations, and the following determination of the probable errors of a single wire in transit-observing was undertaken for this purpose.

After my results had been obtained I became aware of the formula given by M. Struve (" Sur l'Emploi de l'Instrument des Passages"), but as the latitude of the Cape is very different from that of Pulkowa I have thought it well to give my results.

The following is the method I have adopted :—

Assuming the adopted wire intervals to be absolutely correct, the difference of the observed interval between two wires from the computed interval gives the actual error made in measuring a distance by observation at two wires; so that by taking the mean of a large number of such differences we get the "average" error of a distance measured by transit over two wires. If M be this "average" error, or mean of the differences without regard to sign, then

$$\text{probable error of a distance} \qquad = M \times [9{\cdot}927046]$$

and

$$\text{probable error of a transit at one wire} = \frac{M}{\sqrt{2}} \times [9{\cdot}927046].$$

The differences for each star were multiplied by cos (declination) to reduce to the equator, and the stars were grouped in zones according to their North Polar distances. The observations which I have used were made with the transit-circle of the Royal Observatory, Cape of Good Hope, by the three observers who took the chief part in the observations for the Cape Catalogue, 1880; but the period which I found most convenient for my purpose was 1879–1881; the power of the eyepiece used was 180.

The following table gives the probable errors for different N.P.D.'s of an observation at one wire as observed, and also when reduced to their equivalents at the equator :—

TABLE I.

| N.P.D. of Zone. | Mean Z.D. of Zone. | F. p.e. at Obs. | F. No. of Obs. | M. p.e. at Obs. | M. No. of Obs. | P. p.e. at Obs. | P. No. of Obs. | Reduced p.e. F. | Reduced p.e. M. | Reduced p.e. P. |
|---|---|---|---|---|---|---|---|---|---|---|
| ° ° | ° | s | | s | | s | | s | s | s |
| 80–100 | 34 | 0·049 | 208 | 0·086 | 380 | 0·063 | 872 | 0·049 | 0·086 | 0·063 |
| 100–123 | 13 | 0·067 | 271 | 0·094 | 362 | 0·070 | 444 | 0·063 | 0·088 | 0·066 |
| 124–135 | 6 | 0·061 | 163 | 0·084 | 148 | 0·078 | 171 | 0·047 | 0·064 | 0·060 |
| 135–150 | 18 | 0·067 | 239 | 0·092 | 269 | 0·080 | 221 | 0·041 | 0·057 | 0·050 |
| 150–165 | 33 | 0·081 | 263 | 0·110 | 266 | 0·101 | 318 | 0·031 | 0·042 | 0·040 |
| 166–170 | 44 | | | 0·203 | 159 | 0·168 | 194 | | 0·042 | 0·035 |
| 171–174 | 48½ | | | 0·278 | 155 | 0·258 | 279 | | 0·036 | 0·034 |
| 175–177 | 52 | | | 0·483 | 340 | 0·410 | 626 | | 0·034 | 0·029 |
| 178 | 54 | | | 0·891 | 120 | 0·736 | 115 | | 0·031 | 0·026 |
| 179 | 55 | | | 1·408 | 88 | 1·129 | 125 | | 0·025 | 0·020 |
| 181 | 57 | | | 1·367 | 60 | 1·229 | 97 | | 0·024 | 0·022 |
| 182 | 58 | | | 0·789 | 26 | 0·845 | 110 | | 0·028 | 0·029 |
| 183–185 | 60 | | | 0·553 | 443 | 0·475 | 546 | | 0·039 | 0·033 |
| 186–189 | 63½ | | | 0·260 | 42 | 0·302 | 200 | | 0·034 | 0·039 |
| 190–194 | 68 | | | 0·317 | 111 | 0·227 | 216 | | 0·066 | 0·047 |

There were not sufficient observations of circumpolar stars by F in the period 1879–1881 to give a determination of his probable errors beyond 165° N.P.D., and the series for M does not rest on very large numbers of observations except for the zones 175–177 and 183–185. I shall therefore take P as the average observer, and any further conclusions will be based on the figures in the last column of Table I. It will be seen that the probable errors of a single wire by the different observers, though differing in amount, follow the same general law; and that the probable error of observing does not by any means increase in an inverse ratio to the cosine of the star's declination.

If we try to represent our numbers by the formula

$$\text{P.E.}^2 = a^2 + b^2 \sec z \sec^2 \delta,$$

we find

$$a^2 = \cdot 003978, \quad b^2 = \cdot 000564,$$

and therefore

$$\text{P.E.} = \sqrt{(0^s\cdot 063)^2 + (0^s\cdot 024)^2 \sec z \sec^2 \delta}.$$

The representation of the probable errors by this formula, and some variations of it which I have tried, is, however, only moderately satisfactory. The formulæ all failed to give the rapidly diminishing probable errors near the pole. Nor am I surprised at this failure; for, at a distance of 2° or 3° from the pole, the star's disc is in contact with the wire for several seconds,

and the observer practically alters his method of observing: he fixes his attention on the wire and waits till the star's disc is equally distributed on the two sides of it, and this observation can be made with considerable certainty and accuracy.

To find the error in the determination of the azimuth of the instrument introduced by error in observing, divide these probable errors by sin (zenith distance of group), and we get the following table of probable errors of azimuth reduced from a single wire:—

TABLE II.

| N.P.D. of Star. | p.e. of azimuth. | Combination Weight. | Approx. Weight. |
|---|---|---|---|
| $168^\circ$ | $0^s.050$ | 2.45 | 5 |
| $172\frac{1}{2}$ | 0.045 | 3.16 | 6 |
| 176 | 0.036 | 4.57 | 9 |
| 178 | 0.032 | 5.57 | 11 |
| 179 | 0.024 | 10.00 | 20 |
| 181 | 0.026 | | 20 |
| 182 | 0.035 | | 11 |
| 184 | 0.038 | | 9 |
| $187\frac{1}{2}$ | 0.044 | | 6 |
| 192 | 0.051 | | 5 |

so that *four* wires of a star about $178\frac{1}{2}^\circ$ N.P.D. are of as much value in determining the azimuthal error as *sixteen* of a star at $170^\circ$ N.P.D.

We learn another fact from the above table; viz. that at the latitude of the Cape the probable error of the deduced azimuth is the same whether the star be observed above or below the pole; that is to say, the increase of azimuth-factor for the star below pole is counterbalanced by the increased error of observation due to inferior definition at the greater zenith-distance.

The last column in Table II. gives approximate weights for combining azimuthal errors determined from stars at various N.P.D.'s.

*Royal Observatory, Cape of Good Hope:*
1887, *March* 31.

## *Notes on a MS. Eclipse Volume.* By the Rev. S. J. Johnson, M.A.

The accompanying MS. volume * gives eclipses in this country for a period of about 2,000 years, from A.D. 538 to A.D. 2500, being recorded ones of both luminaries from the date of the first in 538 to 1200; all solar eclipses visible here from A.D. 1200 to A.D. 2200, omitting a very few in which scarcely a tenth of the Sun's diameter is obscured, including lunar ones for a certain period and large solar eclipses from A.D. 2200 to A.D. 2500.

It will be seen that during the 1000 years from A.D. 1200 to A.D. 2200 there are only eight cases of an interval so long as that through which we are now passing (May 1882 to June 1890) without a solar eclipse visible in England generally.

The only solar eclipses total at Greenwich in the period of 2000 years are those of 878 and 1715, as has been before remarked, unless, perhaps, that of 664 is an instance. Between the eclipse of 1715 and the preceding one that most nearly approached the total phase at Greenwich, viz. that of 1140, there is an interval of 575 years and a month. A similar interval reckoned forwards from 1715 brings us to A.D. 2290, when there is an eclipse soon after sunrise that seems total in the extreme north of the kingdom. A similar interval reckoned previously to 1140 brings us back to February 565, when the Sun appears to have been totally eclipsed across this country just before setting. Though no ancient chroniclers appear to record this directly, yet Matthew of Westminster says, "In this year there were seen many signs in the Sun and Moon."

*Melplash Vicarage, Dorset:*
*April 28.*

* This volume is placed in the Library.

## *Observations of Saturn and δ Geminorum, Jan.–Feb., 1887.* By John Tebbutt.

The accompanying positions of *Saturn* have been deduced from comparisons of the planet with the clock star δ *Geminorum* about the time of their conjunction. The measures were made with an excellent position filar micrometer on the Grubb 8-inch equatorial refractor, transits of the planet's western limb and the star being observed by means of a half-second chronometer across the single position thread in the meridian, and differences of Declination obtained between the star and the planet's south limb. The micrometer screws have been well tested, one revolution of the screw employed being $17''.869$. The differential Right Ascension and Declination have been corrected for refraction. Corrections due to the planet's semi-diameter (see *Nautical Almanac*, page 282) have been applied to these coordinates and to the times of transit of the limb. The apparent place of the star has been adopted from the *Nautical Almanac*, and the places of the planet have been finally corrected for parallax. As the definition and steadiness of the images were all that could be desired, I have no doubt that the concluded positions will bear favourable comparison with those derived from meridian observations. The last two columns of the table subjoined exhibit a comparison of the results with the places interpolated from the ephemeris on page 258 of the *Nautical Almanac*.

| | Windsor Mean Time. | Planet's Centre—Star $\Delta\alpha$ | Planet's Centre—Star $\Delta\delta$ | Comp. | Planet's Geocentric Apparent $\alpha$ | Planet's Geocentric Apparent $\delta$ | Obs.—N.A. $\alpha$ | Obs.—N.A. $\delta$ |
|---|---|---|---|---|---|---|---|---|
| 1887. d | h m s | m s | ′ ″ | | h m s | ° ′ ″ | s | ″ |
| Jan. 30 | 10 35 10 | +1 58.32 | −0 19.4 | 9 | 7 15 21.79 | +22 10 52.1 | −0.10 | −1.9 |
| Feb. 1 | 10 3 46 | +1 22.15 | +1 0.3 | 20 | 7 14 45.61 | +22 12 11.8 | −0.11 | −0.7 |
| „ 8 | 9 37 38 | −0 36.77 | +5 18.3 | 14 | 7 12 46.66 | +22 16 30.0 | −0.19 | −0.5 |
| „ 9 | 10 9 37 | −0 52.91 | +5 53.3 | 17 | 7 12 30.53 | +22 17 5.1 | −0.18 | −0.5 |
| „ 14 | 10 28 54 | −2 6.86 | +8 34.9 | 12 | 7 11 16.56 | +22 19 46.9 | −0.19 | −0.5 |

*Windsor, N.S. Wales:* 1887, *March* 12.

## *Occultation of a Tauri.* 1887, March 2. By G. L. Tupman.

Notwithstanding the daylight, the Moon's dark limb was plainly visible. *Aldebaran* was very bright and flaring, and hung a long time on the limb without being projected on it more than half of its apparent diameter, which was 10″ or 15″, the reddish colour being very remarkable. By the click of the armature of the transit-clock-relay, at $50^s$ the star suddenly waned, but remained conspicuous until $51^s$, the light lingering, at less than one-half of its original intensity, for fully one second of time. The point of disappearance was on the dark limb, well clear of the terminator.

Having placed a wire tangent to the Moon's bright limb at the calculated point of reappearance, the star was seen to re-appear instantaneously. It was very much less bright at the bright limb than it had before appeared. Watched for 30 seconds there was no further increase of its light. It hung on the limb and was fairly bisected by the latter for a considerable time.

Achromatic of 4½ inches aperture, power 66.

| | Local Sid. Time. h m s | G.M.T. h m s |
|---|---|---|
| Disapp. . . | 4 28 39·5* | 5 49 11·6 |
| Reapp. . . | 4 40 33·4 | 6 1 3·6 |

The occultation was observed by Mr. E. B. Knobel at Bocking, who remarks:—

"The star *glided out* (at the dark limb near the terminator). It did not *snap out* as usual, but there was an appreciable time in its disappearance; it was not an instantaneous phenomenon. The observation was good.

"The reappearance (at the bright limb) seemed instantaneous, but the observation was not quite so good as the immersion. Time between observations 9 minutes 30 seconds."

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## *Sextant Observations of Comet a, 1887, on board the ship "British Merchant."* By Captain E. J. Molony.

(*Communicated by Captain H. Toynbee.*)

1887, *January* 21.—Lat. 28° 17′ S. Long. 21° 25′ W.

At 8 P.M. saw for the first time a comet; a long slightly curved tail, originating in a point towards the Sun, and stretching for 18½° towards the nearest (smallest) Magellan Cloud, from which its visible termination is distant 18°. As the comet is very ill defined and sky cloudy the following distances are approximate. G.M.T. $10^h\ 11^m$:—

* Corresponding to the recorded $50^s$ by the clock.

| | | |
|---|---|---|
| Canopus from head of Comet | ... ... | 75° 10′ |
| *a* Crucis „ „ „ | ... ... | 67 58 |
| Rigel „ „ „ | ... ... | 104 48 |

*January* 22.—Lat. 27° 36′ S. Long. 21° 44′ W. G.M.T. $10^h\ 27^m$. Comet more indistinct. Approximate distances of point:—

| | | |
|---|---|---|
| Canopus | ... .. ... | 73° 50′ |
| *a* Crucis | ... ... ... | 66 38 |
| *a* Arietis | ... ... ... | 91 48 |

*January* 25.—Lat. 23° 4′ S. Long. 24° 27′ W. G.M.T. $10^h\ 37^m$. Comet visible but faint. Approximate distances:—

| | | |
|---|---|---|
| From Canopus | ... ... ... | 66° 10′ |
| „ *a* Crucis | ... ... ... | 66 0 |
| „ Rigel | ... ... ... | 90 30 |

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## *On the Inclinations of Cometary Orbits.* By W. H. S. Monck.

Mr. Chambers in his *Handbook of Descriptive Astronomy* has tabulated the computed cometary orbits up to the year 1876, in which year the last edition of his well-known book was published. He arrives at the conclusion that there is "a decided disposition in the orbits to congregate in and around a plane inclined 50° to the ecliptic." His figures, I think, hardly bear out this result, though on dividing the inclinations into intervals of 10° the largest number appears in the interval between 40° and 50°. But the comets whose orbits are inclined at angles of 70° to 90° amount to sixty-seven, while those whose orbits are inclined at angles of 10° to 30° number only forty-three, both being equally removed from the supposed median plane at 50°.

It occurred to me to examine the orbits of comets which appeared since the publication of Mr. Chambers's List, and I found that the tendency towards orbits inclined at angles of over 50° became much more marked. Many of the earlier orbits being unreliable, however, I thought it best, instead of simply adding the later comets to Mr. Chambers's Table, to tabulate the inclinations of those which have appeared since A.D. 1650, omitting all which are known or believed to be identical. Such a table of course involves some uncertainties, but I believe the following will be found substantially correct:—

*Inclinations of Cometary Orbits to the Ecliptic.*

(Containing only Comets which appeared since A.D. 1650.)

| | | | | | per cent. |
|---|---|---|---|---|---|
| 0° | to | 10° | ... ... | 20 | 7·7 |
| 10 | „ | 20 | ... ... | 19 | 7·3 |
| 20 | „ | 30 | ... ... | 15 | 5·8 |
| 30 | „ | 40 | ... ... | 30 | 11·5 |
| 40 | „ | 50 | ... ... | 37 | 14·2 |
| 50 | „ | 60 | ... ... | 33 | 12·7 |
| 60 | „ | 70 | ... ... | 32 | 12·3 |
| 70 | „ | 80 | ... ... | 37 | 14·2 |
| 80 | „ | 90 | ... ... | 37 | 14·2 |
| | | | Total | 260 | 99·9 |

Here the tendency to a maximum at 50° has entirely disappeared There are in fact more comets in the interval 70° to 90° than in the interval 40° to 60°. But on the other hand there is a very marked deficiency in inclinations from 0° to 30°. In the interval from 30° to 40° we first reach the average number. From 40° to 90° the number is invariably in excess of the average.

If we were at liberty to distinguish comets of short period (which are now known to be pretty numerous) from those which move in very elongated ellipses, parabolas, or hyperbolas, the results would be more striking. Comets of short period have even a more decided preference for small inclinations than the other comets have for large ones. And even if we do not adopt Mr. Proctor's theory, that these comets of short period have been ejected from the planets (especially *Jupiter*), or Professor Kirkwood's suggestion that some at least of them have a common origin with the asteroids, I think there is considerable reason for regarding them as original members of the solar system, exhibiting many of the characteristic properties of that system. If so, it is only to the other and larger class of comets that we can look for information as to the prevailing direction of motions in exterior space; for that their high inclinations to the ecliptic is not caused by anything in the solar system is, I think, certain. A comparison of the inclinations of their orbits with those computed for binary stars would be interesting from this point of view.

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## *On the Orbit of Comet II.* 1883. By Robert Bryant, B.A., B.Sc.

In the *Monthly Notices* for last November Lieut.-General Tennant gave parabolic elements of the orbit of this comet, and expressed his opinion that there is no justification for assigning an orbit with an eccentricity different from unity.

The elliptic elements, which I communicated to the Society in June 1885, depended upon three observations which I considered fairly good ones, and from these the orbit was deduced with great care. The difference between this orbit and that of Lieut.-General Tennant caused me to revise my work and to take into consideration a larger number of observations. Moreover the large residuals given in the middle observed place by Lieut.-General Tennant's parabola seemed to me to indicate that this latter curve scarcely sufficed to represent the observations, and further investigation has confirmed this idea.

As the result of a threefold interpolation the residuals given below were obtained by comparing the observations with the following approximate parabolic elements referred to the mean equator of 1884·0.

| | |
|---|---|
| T | 1883, Dec. $25^{d}\cdot30154$, G.M.T. |
| $\omega'$ | $113^{\circ}\ 36'\ 50''\cdot5$ |
| ☊$'$ | 254 33 46·1 |
| $i'$ | 110 37 51·1 |
| $\log q$ | 9·490993. |

*Observation—Computation.*

| | | R.A. | δ | |
|---|---|---|---|---|
| | | s | " | |
| 1884, Jan. | 12 | +3·17 | −21·0 | Melbourne |
| | 17 | +1·2 | +85·0 | " |
| | 18 | +3·50 | + 1·0 | " |
| | 19 | +2·43 | − 1·8 | Windsor, N.S.W. |
| | 21 | +1·65 | + 4·2 | " |
| | 21 | +2·05 | + 1·1 | " |
| | 22 | +1·87 | − 0·2 | " |
| | 22 | +2·50 | − 1·1 | Madras. |
| | 23 | +1·89 | − 2·3 | Windsor. |
| | 23 | +2·13 | −18·6 | Madras. |
| | 24 | +2·28 | + 2·7 | Windsor. |
| | 25 | +1·76 | − 8·9 | " |
| | 25 | +2·06 | + 6·1 | Madras. |
| | 26 | +2·61 | +23·0 | " |
| | 26 | +3·55 | − 3·2 | " |
| | 27 | +1·07 | − 8·3 | Windsor. |
| | 28 | +2·11 | −12·4 | Melbourne. |
| | 28 | +1·96 | − 0·1 | Windsor. |
| | 28 | +2·37 | − 1·8 | Madras. |
| | 29 | +1·90 | −14·7 | Melbourne. |
| | 30 | +3·26 | +19·0 | Madras. |
| | 31 | +0·19 | + 2·8 | " |
| Feb. | 1 | −0·25 | + 5·1 | Melbourne. |
| | 2 | +2·13 | − 7·8 | Windsor. |
| | 4 | +2·47 | + 0·3 | Melbourne. |

The observations of January 17 and February 1 were rejected for discordance. The observation of January 29 was rejected in order to make the time of the second normal fall at a suitable epoch.

Taking the mean of Tebbutt's observations on January 21, a normal was formed from the observations up to January 22.

Taking the mean of the observations on January 26 and January 28, the second normal was formed from the observations from January 23 to January 28.

Taking the mean of the Madras observations on January 30 and 31, and assigning half weight to the result, the third normal was formed from the remaining observations.

The resulting normals referred to the mean equinox of 1884 January 0·0 are—

| | R.A. | $\delta$ | |
|---|---|---|---|
| (1) | 343° 41′ 0″·7 | −41° 47′ 16″·7 | for 1884 Jan. 19·0 |
| (2) | 350 40 57·7 | −41 59 21·7 | „ 25·0 |
| (3) | 357 13 1·3 | −41 44 16·7 | Feb. 2·0 |

From these normals the elements finally deduced are—

| | | |
|---|---|---|
| T | 1883, Dec. 25ᵈ·233782 | |
| $\omega'$ | 113° 16′ 48″·74 | Mean Equator, 1884·0. |
| ☊′ | 254 32 16·97 | |
| $i'$ | 110 31 34·08 | |
| $e$ | 0·9944387 | |
| log $q$ | 9·4901604 | |
| P | 414 years. | |

Of course any period deduced from an arc of anomaly of only 14° and from an interval of only 14 days is deserving of little confidence.

These elements give the following residuals in the three normal places:—

*Observation—Computation.*

| | | | |
|---|---|---|---|
| Cos $\delta$ $d$R.A. | −0″·6 | −1″·3 | +2″·8 |
| $d\delta$ | 0·0 | −0·3 | −0·1 |

Referred to the ecliptic of 1884·0 the above elements become—

| | | |
|---|---|---|
| T | 1883, Dec. 25ᵈ·233782, G.M.T. | |
| $\omega$ | 138° 17′ 59″·05 | Mean Ecliptic, 1884·0. |
| ☊ | 264 20 17·59 | |
| $i$ | 114 54 0·64 | |
| $e$ | 0·9944387 | |
| log $q$ | 9·4901604. | |

The parabolic elements given by Lieut.-General Tennant on p. 26, vol. xlvii. of the *Monthly Notices*, give the following residuals for the above three normal places :—

*Observation—Computation.*

| | | | |
|---|---|---|---|
| Cos $\delta d$R.A. | $-\ 4''.8$ | $-\ 85''.7$ | $-141''.4$ |
| $d\delta$ | $+612.5$ | $+656.7$ | $+685.3$ |

*Note.*—When the above results were communicated to the Society, I was not in possession of the correction to the inclination of Lieut.-General Tennant's parabola given on p. 394 of the present volume. With this correction the errors (observation—computation) of the parabolic elements are respectively—

| | | | |
|---|---|---|---|
| Cos $\delta d$ R.A. | $-17''.1$ | $-13''.2$ | $+18''.2$ |
| $d\delta$ | $-7.3$ | $-\ 6.5$ | $-\ 2.9$ |

I think the orbit is undoubtedly elliptic, but what the eccentricity is it is impossible to state with certainty.

The Melbourne observations referred to above are those given in the *Astronomische Nachrichten*, and were published after my former paper on this subject was communicated to the Society.

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*The Orbits of Comets Fabry and Barnard-Hartwig.* By J. Morrison, M.D., Ph.D., Assistant on the American Ephemeris, and Professor of Chemistry in the National University, Washington.

*Comet Fabry.*

The observations upon which the following hyperbolic elements of this comet are founded are as follow :—

| Greenwich M.T. | | Appar. $\alpha$ | Appar. $\delta$ |
|---|---|---|---|
| | d | h m s | ° ′ ″ |
| 1885, Dec. | 7.536032 | 0 24 46.01 | +20 52 34.9 |
| 1886, Mar. | 7.316539 | 23 19 42.92 | +31 16 44.8* |
| „ April | 1.339713 | 23 18 30.86 | +38 37 57.0 |
| „ June | 6.953118 | 8 47 52.15 | −40 38 0.5 |

The first is a meridian observation made at Ann Arbor; the second results from extra meridian observations made at Greenwich and Paris, the comparison star being the same at both places; the third was made at Bothkamp and was obtained from *Astronomische Nachrichten*, No. 2703; and the fourth was made at Sydney, the comet being at the time "extremely faint, but in a good position for observation with Cape Cat. (1880) 4707," fifty comparisons having been made. (*Monthly Notices*, vol. xlvi. p. 496.) These observations were corrected for aberration and parallax by means of approximate parabolic elements.

* Geocentric.

| | |
|---|---|
| T | 1886, April $5^{d}\cdot9520$ Greenwich M.T. |
| $\omega$ | $126^{\circ}\ 34'\ 49''\cdot215$ |
| ☊ | $36\ 22\ 11\cdot454$ Mean Equinox, 1886·0 |
| $i$ | $82\ 37\ 6\cdot012$ |
| $e$ | 1·00047857 |
| log $a$ | 3·1278354 |
| log $q$ | 9·8077809 |

The two middle places are well represented.

The interval between the extreme observations is 181·42 days, during which the comet described 208° 9′ of its orbit.

## *Comet Barnard-Hartwig.* 1886.

From the following observations the first and third of which were made at Washington, D.C., and the second at Kiel (*Astronomische Nachrichten*, 2753), an elliptic orbit of long period is obtained, the elements of which are given below :—

| Greenwich M.T. | Appar. $\alpha$. | Appar. $\delta$. |
|---|---|---|
| d | h m s | ° ′ ″ |
| 1886, Oct. 7·918987 | 10 42 9·32 | + 1 22 6·3 |
| „ „ 29·708660 | 11 39 22·82 | + 5 49 19·4 |
| „ Dec. 2·976975 | 15 32 3·91 | +17 58 55·8 |

By means of approximate parabolic elements computed from a shorter interval, the corrections for aberration and parallax were obtained and applied.

| | |
|---|---|
| T | 1886, Dec. $16^{d}\cdot514158$ Greenwich M.T. |
| $\omega$ | $86^{\circ}\ 21'\ 58''\cdot570$ |
| ☊ | $137\ 21\ 36\cdot163$ Mean Equinox, 1886·0 |
| $i$ | $78\ 22\ 25\cdot525$ |
| $e$ | 0·99872521 |
| log $a$ | 2·7162151 |
| log $q$ | 9·8216538 |

Motion retrograde. The middle place is exactly represented. These elements give a period of 11,866 years, which is of course very uncertain, since the interval between the extreme observations is far too short to determine this element accurately in an orbit such as this is.

The formulæ for the equatorial rectangular coordinates are—

$$x=[9\cdot8740086]\,r\sin(v+\ 6^{\circ}\ 52'\ 45''\cdot171)$$
$$y=[9\cdot8268980]\,r\sin(v+198\ 35\ \ 9\cdot651)$$
$$z=[9\cdot9977333]\,r\sin(v+102\ \ 5\ 28\cdot657)$$

*Ephemerides of the Satellites of Mars during the Oppositions of 1888 and 1890.* By J. Morrison, M.D., M.A., Ph.D., Assistant on the American Ephemeris, and Professor of Chemistry, National University, Washington.

These ephemerides have been computed from the following elements of the orbits of the satellites, referred to the equator and equinox of the respective epochs:—

*Phobos.*

| | | |
|---|---|---|
| Epochs | 1888, April 11·0 | 1890, May 27·0 Greenwich M.T. |
| Period | $0^{d}·3189113$ (mean solar) | |
| $\mu$ | $1128^{\circ}·8405$ | |
| $a$ | $12''·953$ (at distance unity) | |
| $i$ | $36^{\circ}\ 44'·6$ | $36^{\circ}\ 44'·0$ |
| N | 47 18·2 | 47 19·0 |
| $u$ | 17 40 | 117 53·6 |

*Deimos.*

| | | |
|---|---|---|
| Epochs | 1888, April 11·0 | 1890, May 27·0 Greenwich M.T. |
| Period | $1^{d}·262435$ (mean solar) | |
| $\mu$ | $285^{\circ}·16322$ | |
| $a$ | $32''·354$ (at distance unity) | |
| $i$ | $35^{\circ}\ 36'$ | $35^{\circ}\ 35'·5$ |
| N | 48 10·66 | 48 11·5 |
| $u$ | 225 41 | 172 21·5 |

*Greenwich Mean Time of Greatest Elongation.*

*Phobos.*

| 1888. | G.M.T. | p | a | b | 1888. | G.M.T. | p | a | b |
|---|---|---|---|---|---|---|---|---|---|
| d | h m | ° | " | " | d | h m | ° | " | " |
| Mar. 21 | 7 53·5 W | 306·4 | 19·1 | 6·1 | Mar. 30 | 6 8·5 W | | | |
| 22 | 10 40·4 E | | | | 31 | 8 55·3 E | | | |
| 23 | 13 27·3 W | | | | Apr. 1 | 11 42·1 W | 305·8 | 20·5 | 6·8 |
| 24 | 16 14·2 E | | | | 2 | 14 29·0 E | | | |
| 25 | 19 1·1 W | | | | 3 | 17 15·8 W | | | |
| 26 | 21 48·0 E | 126·2 | 19·6 | 6·4 | 4 | 20 2·6 E | | | |
| 28 | 0 34·8 W | | | | 5 | 22 49·4 W | | | |
| 29 | 3 21·7 E | | | | 7 | 1 36·1 E | 125·3 | 21·0 | 7·3 |

| 1888. | d | h | m | | p ° | a " | b " |
|---|---|---|---|---|---|---|---|
| Apr. | 8 | 4 | 22·8 | W | | | |
| | 9 | 7 | 9·6 | E | | | |
| | 10 | 9 | 56·3 | W | | | |
| | 11 | 12 | 43·1 | E | | | |
| | 12 | 15 | 29·8 | W | 304·9 | 21·3 | 7·6 |
| | 13 | 18 | 16·6 | E | | | |
| | 14 | 21 | 3·3 | W | | | |
| | 15 | 23 | 50·1 | E | | | |
| | 17 | 2 | 36·9 | W | | | |
| | 18 | 5 | 23·7 | E | 124·4 | 21·4 | 7·8 |
| | 19 | 8 | 10·5 | W | | | |
| | 20 | 10 | 57·2 | E | | | |
| | 21 | 13 | 44·0 | W | | | |
| | 22 | 16 | 30·8 | E | | | |
| | 23 | 19 | 17·6 | W | 303·7 | 21·2 | 8·0 |
| Apr. | 24 | 22 | 4·4 | E | | | |
| | 26 | 0 | 51·3 | W | | | |
| | 27 | 3 | 38·2 | E | | | |
| | 28 | 6 | 25·1 | W | | | |
| | 29 | 9 | 11·9 | E | 123·3 | 21·0 | 8·0 |
| | 30 | 11 | 58·8 | W | | | |
| May | 1 | 14 | 45·8 | E | | | |
| | 2 | 17 | 32·7 | W | | | |
| | 3 | 20 | 19·7 | E | | | |
| | 4 | 23 | 6·7 | W | 302·7 | 20·5 | 8·1 |
| | 6 | 1 | 53·8 | E | | | |
| | 7 | 4 | 40·9 | W | | | |
| | 8 | 7 | 28·0 | E | | | |
| | 9 | 10 | 17·1 | W | | | |
| | 10 | 13 | 4·3 | E | 123·0 | 20·0 | 8·2 |

*Deimos.*

| 1888. | d | h | m | | p ° | a " | b " |
|---|---|---|---|---|---|---|---|
| Mar. | 20 | 15 | 43·4 | E | 125·1 | 47·8 | 15·5 |
| | 22 | 13 | 7·9 | W | | | |
| | 24 | 10 | 32·3 | E | | | |
| | 26 | 7 | 56·5 | W | | | |
| | 28 | 5 | 20·5 | E | | | |
| | 30 | 2 | 44·4 | W | 304·6 | 50·4 | 16·8 |
| Apr. | 1 | 0 | 8·1 | E | | | |
| | 2 | 21 | 31·6 | W | | | |
| | 4 | 18 | 54·9 | E | | | |
| | 6 | 16 | 18·2 | W | | | |
| | 8 | 13 | 41·4 | E | 124·0 | 52·6 | 18·4 |
| | 10 | 11 | 4·5 | W | | | |
| | 12 | 8 | 27·6 | E | | | |
| | 14 | 5 | 50·7 | W | | | |
| | 16 | 3 | 13·8 | E | | | |
| | 18 | 0 | 37·0 | W | 302·9 | 53·5 | 19·6 |
| | 19 | 22 | 0·3 | E | | | |
| | 21 | 19 | 23·6 | W | | | |
| Apr. | 23 | 16 | 47·0 | E | | | |
| | 25 | 14 | 10·7 | W | | | |
| | 27 | 11 | 34·4 | E | 122·1 | 52·6 | 20·1 |
| | 29 | 8 | 58·3 | W | | | |
| May | 1 | 6 | 22·4 | E | | | |
| | 3 | 3 | 46·9 | W | | | |
| | 5 | 1 | 11·9 | E | | | |
| | 6 | 22 | 37·2 | W | 301·4 | 51·2 | 20·1 |
| | 8 | 20 | 2·8 | E | | | |
| | 10 | 17 | 28·6 | W | | | |
| | 12 | 14 | 54·6 | E | | | |
| | 14 | 12 | 20·8 | W | | | |
| | 16 | 9 | 47·1 | E | 121·0 | 50·6 | 20·0 |
| | 18 | 7 | 13·4 | W | | | |
| | 20 | 4 | 39·8 | E | | | |
| | 22 | 2 | 6·4 | W | | | |
| | 23 | 23 | 33·1 | E | | | |
| | 25 | 21 | 0·0 | W | 300·2 | 48·8 | 19·7 |

### *Phobos.*

| 1890. | d | G.M.T. h | m | p | a | b | 1890. | d | G.M.T. h | m | p | a | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ° | ″ | ″ | | | | | ° | ″ | ″ |
| May | 8 | 0 | 44·8 E | 123·6 | 23·5 | 2·3 | June | 7 | 3 | 52·1 W | | | |
| | 9 | 3 | 31·8 W | | | | | 8 | 6 | 39·0 E | | | |
| | 10 | 6 | 18·8 E | | | | | 9 | 9 | 26·0 W | | | |
| | 11 | 9 | 5·8 W | | | | | 10 | 12 | 12·9 E | 126·7 | 26·5 | 5·3 |
| | 12 | 11 | 52·8 E | | | | | 11 | 14 | 59·9 W | | | |
| | 13 | 14 | 39·8 W | 304·1 | 25·0 | 3·0 | | 12 | 17 | 46·8 E | | | |
| | 14 | 17 | 26·8 E | | | | | 13 | 20 | 33·8 W | | | |
| | 15 | 20 | 13·8 W | | | | | 14 | 23 | 20·8 E | | | |
| | 16 | 23 | 0·8 E | | | | | 16 | 2 | 7·7 W | 307·1 | 26·0 | 5·6 |
| | 18 | 1 | 47·8 W | | | | | 17 | 4 | 54·8 E | | | |
| | 19 | 4 | 34·7 E | 124·5 | 25·4 | 3·3 | | 18 | 7 | 41·7 W | | | |
| | 20 | 7 | 21·7 W | | | | | 19 | 10 | 28·9 E | | | |
| | 21 | 10 | 8·6 E | | | | | 20 | 13 | 16·0 W | | | |
| | 22 | 12 | 55·6 W | | | | | 21 | 16 | 3·2 E | 127·3 | 25·5 | 5·7 |
| | 23 | 15 | 42·5 E | | | | | 22 | 18 | 50·2 W | | | |
| | 24 | 18 | 29·5 W | 305·0 | 26·0 | 3·8 | | 23 | 21 | 37·4 E | | | |
| | 25 | 21 | 16·4 E | | | | | 25 | 0 | 24·6 W | | | |
| | 27 | 0 | 3·3 W | | | | | 26 | 3 | 11·9 E | | | |
| | 28 | 2 | 50·2 E | | | | | 27 | 5 | 59·2 W | 307·5 | 24·9 | 5·7 |
| | 29 | 5 | 37·0 W | | | | | 28 | 8 | 46·4 E | | | |
| | 30 | 8 | 23·9 E | 125·6 | 26·3 | 4·3 | | 29 | 11 | 33·7 W | | | |
| | 31 | 11 | 10·8 W | | | | | 30 | 14 | 21·0 E | | | |
| June | 1 | 13 | 57·6 E | | | | July | 1 | 17 | 8·3 W | | | |
| | 2 | 16 | 44·6 W | | | | | 2 | 19 | 55·6 E | 127·7 | 24·1 | 5·7 |
| | 3 | 19 | 31·4 E | | | | | 3 | 22 | 42·9 W | | | |
| | 4 | 22 | 18·4 W | 306·1 | 26·7 | 4·8 | | 5 | 1 | 30·2 E | | | |
| | 6 | 1 | 5·2 E | | | | | 6 | 4 | 17·6 W | | | |

### *Deimos.*

| 1890. | d | G.M.T. h | m | p | a | b | 1890. | d | G.M.T. h | m | p | a | b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ° | ″ | ″ | | | | | ° | ″ | ″ |
| Apr. | 30 | 22 | 40·9 E | 122·5 | 55·1 | 5·6 | May | 16 | 2 | 3·6 E | | | |
| May | 2 | 20 | 6·9 W | | | | | 17 | 23 | 28·0 W | | | |
| | 4 | 17 | 32·7 E | | | | | 19 | 20 | 52·3 E | 124·0 | 63·7 | 9·4 |
| | 6 | 14 | 58·3 W | | | | | 21 | 18 | 16·6 W | | | |
| | 8 | 12 | 23·6 E | | | | | 23 | 15 | 40·9 E | | | |
| | 10 | 9 | 48·9 W | 303·1 | 59·7 | 7·2 | | 25 | 13 | 5·1 W | | | |
| | 12 | 7 | 14·0 E | | | | | 27 | 10 | 29·1 E | | | |
| | 14 | 4 | 38·9 W | | | | | 29 | 7 | 53·1 W | 304·9 | 66·1 | 11·8 |

| | | G.M.T. | | | *p* | *a* | *b* | | | G.M.T. | | | *p* | *a* | *b* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1890. | d | h | m | | ° | " | " | 1890. | d | h | m | | ° | " | " |
| May | 31 | 5 | 17·1 | E | | | | June | 19 | 3 | 21·4 | E | | | |
| June | 2 | 2 | 41·1 | W | | | | | 21 | 0 | 46·7 | W | | | |
| | 4 | 0 | 5·3 | E | | | | | 22 | 22 | 12·3 | E | | | |
| | 5 | 21 | 29·4 | W | | | | | 24 | 19 | 38·1 | W | | | |
| | 7 | 18 | 53·6 | E | 125·6 | 66·6 | 13·8 | | 26 | 17 | 4·1 | E | 126·5 | 62·1 | 15·2 |
| | 9 | 16 | 17·9 | W | | | | | 28 | 14 | 30·3 | W | | | |
| | 11 | 13 | 42·4 | E | | | | | 30 | 11 | 56·6 | E | | | |
| | 13 | 11 | 6·9 | W | | | | July | 2 | 9 | 23·1 | W | | | |
| | 15 | 8 | 31·5 | E | | | | | 4 | 6 | 49·8 | E | | | |
| | 17 | 5 | 56·3 | W | 306·1 | 65·6 | 14·8 | | 6 | 4 | 16·8 | W | 306·6 | 57·6 | 14·5 |

In these ephemerides $p$ denotes the position-angle of the major axis of the satellite's apparent orbit, and is reckoned from the north towards the east, and from 0° to 360°; $a$ and $b$ denote the major and minor semi-axes of the apparent orbit. During these two oppositions of the planet the satellites move in the direction of *increasing* position-angles, the Earth being *above* the plane of the orbits. The time of greatest elongation has been given to the nearest tenth of a minute in order that a sufficiently accurate comparison may be had with observation.

# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY.

VOL. XLVII. JUNE 10, 1887 No. 8


J. W. L. GLAISHER, M.A., Sc.D., F.R.S., President, in the Chair.

Lieut. Arthur Mostyn Field, R.N., H.M.S. "Dart";
Herbert Ingall, Champion Grove, Champion Hill, S.W.;
Henry Addenbrook Wassell, Addenbrook Villa, Love Lane, Stourbridge; and
The Rev. Charles John Young, Stafford Place, Halifax,
were balloted for and duly elected Fellows of the Society.

Admiral E. Mouchez, Director of the Observatory, Paris, was balloted for and duly elected an Associate of the Society.

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*Proposed Index to Observations of Variable Stars.* By Professor Edward C. Pickering.

For the last four years the Observatory of Harvard College has published an annual statement of the number of observations made during the previous year upon each variable star. In the fifth of these publications—to be published during 1888—it is proposed to give a statement of the number of dates of observation of each variable star during each year since its discovery. It is hoped that an index of this kind will be useful to astronomers, even if it cannot be made complete; but its value will certainly be much increased by the addition of every extensive list of observations which can be obtained for insertion in it. All who are interested in this department of astronomy are therefore requested to send to this observatory any information of the

kind above described which they may have at command. It is very desirable that the information should be received early in 1888, in order that the publication may not be unduly delayed.

*Harvard College Observatory, Cambridge, U.S.A.:*
1887, *June* 22.

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## *On the Parallax of* $61_1$ *and* $61_2$ Cygni, *as obtained by the aid of Photography.* By Professor C. Pritchard, D.D., F.R.S.

The computations for the parallax of the two components of this historical double star are now completed, subject to some possible slight revision of the numerical work.

Inasmuch as the present communication professes to be nothing more than a preliminary and provisional announcement, perhaps the most interesting form of making it may be to give a short citation from the Report of the astronomical work done at the University Observatory in Oxford during the past year. It will be seen in the sequel that it is not without some importance to add that the Report was approved and adopted by the Vice-Chancellor and other members of the Board of Visitors, including the Astronomer-Royal.

The following is the citation referred to:—

"The somewhat hazardous enterprise of attempting for the first time in the history of astronomy to obtain the distance of fixed stars from our earth by the aid of photography has been attended with success. The final results of the investigation have been placed in my hands only during the writing of this Report. The first observation was obtained on May 26 of last year, and the last was effected on May 31 of the present year. The intermediate computations were systematically continued during the interval. They involved the reduction of no less than 30,000 bisections of star-images, on 330 photographic plates, procured on 89 nights. Eight independent determinations of the parallax of the two components of 61 *Cygni* resulted from all this work, and these happily indicate a substantial agreement between themselves, and afford other necessary proof of reliability. Astronomical photography is hereby placed on a secure basis as an efficient and exact exponent of the highest form of astronomical science.

"Simultaneously with these observations similar work has been in progress for the determination of the parallax of $\mu$ *Cassiopeiæ* and *Polaris*. These observations will now be treated on a less laborious scale. The photographic plates of the *Pleiades* have also been taken with the view of obtaining the accurate relative positions of about one hundred stars therein. The necessary triangulations have been commenced.

"The funds granted by the University have been sufficient notwithstanding the continuous activity, which requires a cor-

responding continuity of outlay. This grant, hitherto triennial, expires in December next. If the Board of Visitors see fit to request the University to continue this grant for five years, it would assist in enabling me to commence a valuable and extended class of work, which under other circumstances I should not be justified in attempting."

This last sentence was altered by the Board of Visitors into "to undertake for the University a share in the production of a photographic map of the heavens."

The details given above testify without further words of mine to the unwearied perseverance and intelligence of my two able assistants Mr. Plummer and Mr. Jenkins.

The following are the particulars of the final numerical results referred to in the foregoing citation:—

| *Parallax of* $61_1$ *Cygni.* | | *Parallax of* $61_2$ *Cygni.* | |
|---|---|---|---|
| Determined from star | $a = 0''.4294$ | from star | $a = 0''.4250$ |
| | $b = 0.4228$ | | $b = 0.4508$ |
| | $x = 0.4441$ | | $x = 0.4520$ |
| | $y = 0.4194$ | | $y = 0.4135$ |
| Mean | $= 0.4289$ | Mean | $= 0.4353$ |

Mean probable error of a single determination of

$$61_1 \text{ Cygni} = 0''.0136.$$
$$61_2 \text{ Cygni} = 0.0142.$$

Mean distance of star $a$ from $b = 2382''.20$
$x$ from $y = 2066.16$

Distance $a$ to $b$ fluctuates from $2380''.84$ to $2382''.89$
$x$ to $y$ 2064.80 to 2066.86.

*Oxford University Observatory:*
1887, *June* 10.

*Postscript* (*June* 24).—The very important significance of the above figures is twofold:

1. That in order to arrive at exactness of angular measure in a photograph, and especially in a series of photographs carried through considerable periods of time, it is absolutely necessary that each plate should be considered as carrying with it its own scale, which scale may be slightly variable from night to night, or even during the same night. This fact is indicated by the small variations in the distances of the comparison stars $a$, $b$, and $x$, $y$ from each other. This fact, however, is not peculiar to photographic plates, but exists (to a less extent) even in measures taken with the heliometer.

2. That if due regard be had to this slight variation of scale, photography, properly handled, gives reliable results, equal in accuracy and delicacy to those obtainable by any other known astronomical methods.

Since the writing of the foregoing very succinct and provisional account of work recently completed at the University Observatory, Dr. De la Rue, with that munificent generosity which he has so often exercised for the promotion of knowledge, has promised the pecuniary means of adding a photographic telescope or camera to the large Refractor in that institution. The condition attached to this gift is the compliance of the University with the request made, as above stated, by the Board of Visitors. Oxford, therefore, may now be expected to be associated with Greenwich in the production of the great international photographic chart of the heavens projected at the Paris Conference.

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*A Comparison of the Star-Places of the Argentine General Catalogue for* 1875 *with those of the Cape Catalogue for* 1880, *and with those of other Southern Star Catalogues.* By A. M. W. Downing, M.A.

In making this comparison the places of those stars which are common to the Argentine General Catalogue and the Cape Catalogue for 1880, as given in the former, have been brought up from 1875 to 1880, and the differences, Cordoba—Cape, taken. Proper motion has been applied in forming both the Cordoba mean places for 1875 and the annual variations in all those cases in which a proper motion is given in the Cape Catalogue, the quantity of proper motion being taken from the latter. The mean epochs of the two Catalogues are, however, so nearly identical that this element can have no sensible effect on the result deduced from such a large number of stars as is the present. In combining the separate differences, formed as is explained above, each hour of R.A. has been taken by itself, and the stars occurring in each hour arranged in order of N.P.D., and then the means taken over zones 10° wide for the extremes, 90°—100°, 100°—110°, and 170°—180°, and 5° wide for intermediate N.P.D.s. In this manner the table (Table I.) has been formed, exhibiting the values of Cordoba—Cape, both for R.A. and N.P.D., corresponding to each hour of R.A. and to each zone of N.P.D., and the number of stars (always the same for $\Delta\alpha$ and $\Delta\delta$) in each group. It will of course be understood that the R.A.s of these two Catalogues depend on different systems of time-stars. In the formation of the Argentine Catalogue the star-places of the *American Ephemeris* for the different years were used; the Cape R.A.s depend on the annual lists of fundamental stars issued from the Greenwich Observatory.

The next table (Table II.) is formed by taking the means of the differences occurring in each horizontal line of Table I., and thus forming the mean difference in R.A. and N.P.D. over the whole range of N.P.D. corresponding to each hour of R.A.

The next table (Table III.) is formed from the means of vertical columns in Table I., and exhibits the mean differences in R.A. and N.P.D. over the whole range of R.A. corresponding to the different zones in which the N.P.D.s have been combined. To enable the reader better to estimate the range of the discordances in R.A. the differences corresponding to each zone of N.P.D. are given reduced to the equator, as well as the actual mean discordances at the different N.P.D.s.

It will be noticed that there is a remarkable break of continuity in the value of $\Delta\delta$ (as exhibited in Table III.) corresponding to the zone 140°—145°, and in that corresponding to 145°—150°, the value being $+0^s \cdot 088$ for the former, and $+0^s \cdot 006$ for the latter, or $+0^s \cdot 054$ and $+0^s \cdot 003$ respectively, expressed in equatorial interval. As the former of these mean differences depends on 1,229 stars, and the latter on 1,179 stars, this break cannot be considered accidental, and the general agreement is so good (except for stars in the immediate neighbourhood of the pole) that, though the actual quantities are small, the attention is arrested by the abrupt change.

The negative differences in N.P.D. appear to increase in magnitude as the northern limit is approached, being $-0'' \cdot 73$ for the zone 90°—100°. The difference for the zone 165°—170° is also abnormally large, though depending on a considerable number of stars.

It will be remarked that the mean discordance in R.A. is $+0^s \cdot 047$ ($+0^s \cdot 036$ reduced to the equator), and in N.P.D $-0'' \cdot 40$, and that the total number of stars used in the comparison is 11,752.

The next step has been to obtain the values of $\Delta\alpha$ and $\Delta\delta$ for the beginning of each hour of R.A. and for each 5° of N.P.D. by means of a graphical representation of the changes of these values taken from Tables II. and III., it being assumed that the mean value corresponding to a certain hour of R.A. or to a certain zone of N.P.D. refers to the middle of the hour or of the zone. The $\Delta\alpha$s and $\Delta\delta$s read off from their appropriate curves for the beginning of each hour of R.A. have been respectively corrected by the quantities $-0^s \cdot 047$ and $+0'' \cdot 40$ (the means, with reversed signs, of the $\Delta\alpha$s and $\Delta\delta$s taken throughout), so that the difference Cordoba—Cape for any given R.A. and N.P.D. is the sum of the quantities corresponding to that R.A. and N.P.D. as given in the tables (Tables IV. and V.). From the comparisons published in *Monthly Notices*, vol. xlii. pp. 22, 23, vol. xlv. pp. 298–301, and vol. xlvi. pp. 366–379, in connection with the comparison of the Argentine General Catalogue and the Cape Catalogue for 1880, forming the first parts of Tables IV. and V., the remaining portions have been formed, and these

tables therefore give the corrections applicable to the Cape Catalogue for 1880, the Melbourne Catalogue for 1870, and the Cape Catalogues for 1860, 1850, and 1840, to reduce them respectively to the system of the Argentine General Catalogue for 1875.

It is remarkable that the differences in R.A. depending on N.P.D. of the Cordoba and Cape 1880 Catalogues at about 130°—140° are very nearly equal in magnitude, but *of opposite sign*, to those of the Cordoba and Cape 1850 Catalogues at the same N.P.D., the discordances of which at about this place have been the subject of considerable discussion (Introduction to Cape Catalogue for 1850, p. xi., *Monthly Notices*, vol. xlv. p. 38).

I should add that the expenses of the computations, the results of which are embodied in this paper, have been defrayed by a grant from the Government Grant Committee of the Royal Society, to whom my thanks are due.

TABLE I.

| N.P.D. | 90°–100° | | | 100°–110° | | | 110°–115° | | |
|---|---|---|---|---|---|---|---|---|---|
| R.A. | Δα | Δδ | No. | Δα | Δδ | No. | Δα | Δδ | No. |
| h h | s | ″ | | s | ″ | | s | ″ | |
| 0–1 | −·002 | −0·66 | 19 | +·004 | +0·03 | 14 | +·015 | −0·44 | 21 |
| 1–2 | +·003 | −0·34 | 17 | −·020 | −0·29 | 12 | +·008 | −0·33 | 18 |
| 2–3 | +·007 | −0·56 | 23 | +·040 | −0·32 | 6 | +·007 | −0·71 | 27 |
| 3–4 | +·014 | −1·01 | 18 | +·050 | −0·87 | 6 | +·017 | −0·74 | 15 |
| 4–5 | +·026 | −0·69 | 20 | +·019 | −0·36 | 9 | +·020 | −0·09 | 13 |
| 5–6 | +·037 | −0·86 | 45 | +·069 | −0·65 | 15 | +·072 | +0·08 | 13 |
| 6–7 | +·043 | −0·63 | 12 | +·093 | −0·84 | 19 | +·079 | −0·30 | 33 |
| 7–8 | +·090 | −1·07 | 13 | +·049 | −1·27 | 17 | +·098 | −0·28 | 26 |
| 8–9 | +·031 | −0·96 | 13 | +·090 | −1·22 | 12 | +·093 | −0·17 | 10 |
| 9–10 | +·080 | −1·14 | 28 | +·061 | −1·01 | 11 | +·002 | +0·55 | 9 |
| 10–11 | +·030 | −0·72 | 27 | +·078 | −1·26 | 10 | +·057 | +0·19 | 7 |
| 11–12 | +·026 | −0·68 | 15 | +·036 | −0·71 | 12 | +·072 | +0·18 | 10 |
| 12–13 | +·083 | +0·43 | 3 | −·010 | −0·95 | 2 | +·073 | +0·11 | 16 |
| 13–14 | +·070 | −0·91 | 4 | −·004 | −0·80 | 5 | +·082 | +0·40 | 9 |
| 14–15 | +·048 | −0·34 | 4 | +·048 | −0·24 | 4 | +·019 | +0·27 | 16 |
| 15–16 | −·015 | −0·68 | 2 | −·030 | −0·35 | 5 | +·043 | +0·23 | 27 |
| 16–17 | +·010 | −0·16 | 4 | +·008 | +0·23 | 4 | +·032 | +0·50 | 23 |
| 17–18 | −·040 | −1·00 | 3 | +·017 | −1·85 | 3 | +·050 | +0·18 | 22 |
| 18–19 | +·005 | −1·59 | 4 | ·000 | −0·72 | 1 | +·028 | −0·13 | 21 |
| 19–20 | −·015 | −0·78 | 2 | −·014 | +0·21 | 5 | +·075 | −0·20 | 17 |
| 20–21 | −·020 | −0·48 | 5 | +·008 | −0·42 | 5 | +·058 | −0·37 | 18 |
| 21–22 | +·040 | −0·17 | 3 | +·005 | −0·36 | 6 | +·007 | −0·52 | 17 |
| 22–23 | −·004 | −0·19 | 7 | +·016 | −0·78 | 10 | +·018 | −0·76 | 21 |
| 23–24 | −·029 | −0·23 | 10 | +·039 | −0·82 | 17 | +·032 | −0·59 | 19 |

| N.P.D. | 115°–120° | | | 120°–125° | | | 125°–130° | | |
|---|---|---|---|---|---|---|---|---|---|
| R.A. | Δα | Δδ | No. | Δα | Δδ | No. | Δα | Δδ | No. |
| h h | s | ″ | | s | ″ | | s | ″ | |
| 0–1 | +·075 | −0·64 | 28 | +·100 | −1·03 | 32 | +·024 | −0·55 | 44 |
| 1–2 | +·077 | −0·45 | 23 | +·074 | −0·76 | 36 | +·017 | −0·56 | 38 |
| 2–3 | +·012 | −0·53 | 34 | +·059 | −0·83 | 40 | +·023 | −0·43 | 42 |
| 3–4 | +·016 | −0·48 | 41 | +·047 | −0·55 | 39 | +·036 | −0·25 | 46 |
| 4–5 | +·017 | −0·32 | 36 | +·078 | −0·40 | 41 | +·034 | −0·12 | 60 |
| 5–6 | +·096 | −0·28 | 41 | +·122 | −0·46 | 50 | +·088 | +0·17 | 57 |
| 6–7 | +·093 | −0·22 | 76 | +·128 | −0·26 | 64 | +·108 | +0·09 | 55 |
| 7–8 | +·108 | −0·08 | 62 | +·135 | −0·17 | 57 | +·110 | +0·18 | 89 |
| 8–9 | +·058 | −0·07 | 52 | +·093 | −0·13 | 62 | +·094 | +0·12 | 68 |
| 9–10 | +·056 | −0·14 | 59 | +·082 | −0·25 | 49 | +·063 | −0·01 | 48 |
| 10–11 | +·017 | −0·07 | 33 | +·064 | −0·18 | 38 | +·057 | −0·13 | 44 |
| 11–12 | +·079 | 0·00 | 45 | +·095 | −0·29 | 46 | +·073 | −0·03 | 47 |
| 12–13 | +·086 | +0·08 | 34 | +·082 | −0·37 | 41 | +·112 | −0·17 | 33 |
| 13–14 | +·073 | +0·15 | 38 | +·057 | −0·25 | 46 | +·111 | −0·30 | 42 |
| 14–15 | +·039 | +0·36 | 53 | +·083 | −0·10 | 51 | +·085 | −0·11 | 43 |
| 15–16 | +·028 | +0·14 | 49 | +·082 | −0·16 | 48 | +·055 | −0·08 | 63 |
| 16–17 | +·048 | +0·16 | 50 | +·049 | −0·30 | 70 | +·061 | −0·33 | 50 |
| 17–18 | −·013 | −0·12 | 49 | +·040 | −0·27 | 70 | +·020 | −0·21 | 76 |
| 18–19 | +·025 | −0·24 | 56 | +·031 | −0·70 | 70 | +·046 | −0·49 | 62 |
| 19–20 | +·034 | −0·05 | 38 | +·065 | −0·66 | 37 | +·020 | −0·38 | 51 |
| 20–21 | +·043 | −0·43 | 51 | +·067 | −1·08 | 42 | +·001 | −0·67 | 34 |
| 21–22 | +·028 | −0·68 | 48 | +·096 | −0·60 | 25 | +·035 | −0·59 | 39 |
| 22–23 | +·054 | −0·65 | 42 | +·072 | −1·01 | 27 | +·027 | −0·53 | 35 |
| 23–24 | +·060 | −0·52 | 34 | +·052 | −0·65 | 33 | +·017 | −0·58 | 33 |

| N.P.D. | 130°–135° | | | 135°–140° | | | 140°–145° | | |
|---|---|---|---|---|---|---|---|---|---|
| R.A. | Δα | Δδ | No. | Δα | Δδ | No. | Δα | Δδ | No. |
| h h | s | ″ | | s | ″ | | s | ″ | |
| 0–1 | +·037 | −0·46 | 43 | +·075 | −0·65 | 26 | +·005 | −0·73 | 48 |
| 1–2 | +·055 | −0·40 | 34 | +·098 | −0·55 | 30 | +·043 | −0·86 | 47 |
| 2–3 | +·016 | −0·32 | 42 | +·061 | −0·81 | 23 | +·035 | −0·52 | 44 |
| 3–4 | +·033 | +0·06 | 46 | +·028 | −0·22 | 38 | +·044 | −0·40 | 42 |
| 4–5 | +·049 | −0·13 | 47 | +·047 | −0·12 | 30 | +·041 | −0·38 | 46 |
| 5–6 | +·088 | +0·20 | 50 | +·066 | −0·45 | 41 | +·107 | −0·47 | 52 |
| 6–7 | +·084 | +0·49 | 67 | +·118 | −0·25 | 48 | +·125 | −0·28 | 64 |
| 7–8 | +·108 | +0·12 | 69 | +·118 | −0·12 | 64 | +·139 | −0·27 | 85 |
| 8–9 | +·071 | −0·04 | 76 | +·106 | −0·24 | 108 | +·103 | −0·29 | 93 |
| 9–10 | +·059 | 0·00 | 42 | +·138 | −0·26 | 64 | +·131 | −0·50 | 70 |
| 10–11 | +·039 | +0·08 | 55 | +·095 | −0·45 | 56 | +·080 | −0·17 | 74 |
| 11–12 | +·061 | +0·15 | 34 | +·124 | −0·31 | 56 | +·077 | −0·16 | 51 |
| 12–13 | +·114 | −0·07 | 36 | +·180 | −0·60 | 44 | +·159 | −0·49 | 45 |

| N.P.D. | 130°–135° | | | 135°–140° | | | 140°–145° | | |
|---|---|---|---|---|---|---|---|---|---|
| R.A. | Δα | Δδ | No. | Δα | Δδ | No. | Δα | Δδ | No. |
| h h | s | " | | s | " | | s | " | |
| 13–14 | +·092 | −0·09 | 57 | +·137 | −0·62 | 56 | +·142 | −0·47 | 55 |
| 14–15 | +·119 | −0·22 | 47 | +·148 | −0·44 | 54 | +·161 | −0·48 | 36 |
| 15–16 | +·053 | −0·21 | 70 | +·119 | −0·53 | 49 | +·134 | −0·39 | 49 |
| 16–17 | +·071 | −0·24 | 65 | +·088 | −0·63 | 63 | +·074 | −0·63 | 52 |
| 17–18 | +·047 | −0·24 | 54 | +·055 | −0·49 | 79 | +·073 | −0·68 | 38 |
| 18–19 | +·050 | −0·56 | 54 | +·087 | −0·85 | 63 | +·109 | −0·65 | 37 |
| 19–20 | +·026 | −0·54 | 36 | +·108 | −0·69 | 30 | +·079 | −0·84 | 39 |
| 20–21 | +·048 | −0·68 | 55 | +·043 | −0·89 | 32 | +·072 | −0·78 | 28 |
| 21–22 | +·041 | −0·51 | 28 | +·049 | −1·21 | 32 | +·028 | −0·82 | 40 |
| 22–23 | +·085 | −0·51 | 38 | +·038 | −0·81 | 39 | +·010 | −0·84 | 44 |
| 23–24 | +·053 | −0·51 | 52 | +·081 | −0·77 | 31 | +·033 | −0·70 | 50 |

| N.P.D. | 145°–150° | | | 150°–155° | | | 155°–160° | | |
|---|---|---|---|---|---|---|---|---|---|
| R.A. | Δα | Δδ | No. | Δα | Δδ | No. | Δα | Δδ | No. |
| h h | s | " | | s | " | | s | " | |
| 0–1 | −·020 | −0·48 | 35 | +·039 | −0·24 | 19 | +·047 | −0·34 | 15 |
| 1–2 | +·001 | −0·45 | 29 | −·029 | −0·34 | 23 | −·026 | −0·23 | 17 |
| 2–3 | +·036 | −0·63 | 31 | +·098 | −0·26 | 33 | −·024 | −0·02 | 23 |
| 3–4 | +·061 | −0·60 | 34 | +·080 | −0·33 | 32 | +·007 | −0·32 | 23 |
| 4–5 | +·039 | −0·32 | 45 | +·049 | −0·47 | 35 | −·040 | −0·62 | 25 |
| 5–6 | −·003 | −0·47 | 51 | −·012 | −0·27 | 36 | −·019 | −0·40 | 31 |
| 6–7 | −·045 | −0·37 | 44 | −·018 | −0·03 | 35 | +·055 | −0·69 | 27 |
| 7–8 | +·020 | −0·76 | 73 | +·022 | −0·25 | 31 | +·056 | −0·73 | 29 |
| 8–9 | +·003 | −0·50 | 60 | +·051 | −0·46 | 35 | +·020 | −0·59 | 33 |
| 9–10 | +·018 | −0·43 | 78 | +·013 | −0·38 | 47 | +·027 | −0·67 | 34 |
| 10–11 | −·001 | −0·45 | 109 | −·018 | −0·48 | 79 | +·008 | −0·44 | 27 |
| 11–12 | +·054 | −0·52 | 72 | +·017 | −0·33 | 86 | +·066 | −0·64 | 28 |
| 12–13 | +·041 | −0·46 | 59 | +·037 | −0·20 | 44 | +·083 | −0·47 | 35 |
| 13–14 | +·035 | −0·47 | 48 | +·026 | −0·42 | 55 | +·066 | −0·52 | 37 |
| 14–15 | +·042 | −0·42 | 50 | +·026 | −0·46 | 32 | +·054 | −0·54 | 32 |
| 15–16 | −·051 | −0·58 | 47 | +·017 | −0·30 | 36 | +·012 | −0·40 | 26 |
| 16–17 | −·006 | −0·28 | 45 | −·002 | −0·41 | 31 | +·072 | −0·45 | 25 |
| 17–18 | −·001 | −0·63 | 45 | −·016 | −0·14 | 32 | +·052 | −0·19 | 16 |
| 18–19 | −·074 | −0·78 | 40 | +·020 | −0·40 | 35 | +·043 | −0·05 | 16 |
| 19–20 | −·005 | −0·48 | 34 | −·057 | −0·40 | 19 | +·068 | −0·44 | 32 |
| 20–21 | −·055 | −0·42 | 19 | +·008 | −0·55 | 29 | +·071 | −0·31 | 18 |
| 21–22 | −·008 | −0·84 | 51 | +·010 | −0·50 | 24 | +·074 | −0·65 | 9 |
| 22–23 | −·005 | −0·82 | 39 | +·039 | −0·43 | 25 | +·145 | −0·57 | 11 |
| 23–24 | −·027 | −0·85 | 41 | +·008 | −0·34 | 27 | +·154 | −0·51 | 17 |

| N.P.D. | 160°-165° | | | 165°-170° | | | 170°-180° | | |
|---|---|---|---|---|---|---|---|---|---|
| R.A. | Δα | Δδ | No. | Δα | Δδ | No. | Δα | Δδ | No. |
| h h | s | ″ | | s | ″ | | s | ″ | |
| 0-1 | +·041 | −0·25 | 22 | −·068 | −0·97 | 25 | −·169 | −0·29 | 13 |
| 1-2 | −·078 | −0·35 | 18 | −·023 | −0·73 | 23 | −·064 | −0·32 | 17 |
| 2-3 | +·078 | −0·07 | 16 | +·184 | −0·67 | 16 | +·105 | −0·13 | 11 |
| 3-4 | +·034 | +0·09 | 20 | −·030 | −0·62 | 21 | −·011 | +0·34 | 15 |
| 4-5 | +·004 | −0·33 | 16 | −·102 | −0·52 | 14 | −·337 | −0·12 | 11 |
| 5-6 | −·022 | −0·35 | 20 | −·067 | −0·86 | 15 | −·222 | −0·70 | 9 |
| 6-7 | +·048 | −0·66 | 20 | −·109 | −0·64 | 14 | −·261 | −0·90 | 11 |
| 7-8 | +·067 | −0·74 | 22 | −·050 | −1·34 | 15 | −·171 | −0·96 | 11 |
| 8-9 | +·060 | −0·50 | 28 | −·090 | −1·26 | 23 | −·280 | −1·44 | 7 |
| 9-10 | ·000 | −0·69 | 22 | −·076 | −1·90 | 19 | −·066 | −0·75 | 20 |
| 10-11 | −·033 | −0·52 | 19 | −·066 | −1·13 | 18 | −·161 | −0·87 | 19 |
| 11-12 | +·123 | −0·32 | 27 | +·027 | −1·42 | 17 | −·269 | −0·57 | 11 |
| 12-13 | +·074 | −0·44 | 24 | +·098 | −1·12 | 13 | −·061 | −0·87 | 11 |
| 13-14 | +·056 | −0·64 | 17 | +·003 | −0·86 | 12 | −·103 | −0·98 | 10 |
| 14-15 | −·041 | −0·54 | 20 | −·048 | −1·25 | 20 | −·038 | −0·87 | 11 |
| 15-16 | −·043 | +0·19 | 27 | +·002 | −0·77 | 19 | −·525 | +0·43 | 2 |
| 16-17 | +·032 | +0·01 | 20 | +·106 | −0·90 | 16 | +·060 | +0·14 | 10 |
| 17-18 | +·005 | 0·00 | 16 | +·010 | −0·79 | 14 | +·043 | −0·32 | 12 |
| 18-19 | +·080 | +0·10 | 18 | +·055 | −0·88 | 11 | +·100 | −0·74 | 12 |
| 19-20 | −·063 | −0·42 | 26 | −·079 | −1·01 | 16 | −·163 | −0·33 | 3 |
| 20-21 | +·056 | −0·11 | 25 | −·102 | −0·62 | 25 | −·044 | −0·15 | 17 |
| 21-22 | −·011 | −0·24 | 26 | −·047 | −1·16 | 16 | −·151 | +0·11 | 17 |
| 22-23 | +·024 | −0·20 | 15 | −·105 | −0·98 | 17 | −·092 | −0·47 | 11 |
| 23-24 | +·070 | −0·56 | 20 | +·006 | −0·51 | 8 | −·266 | −0·51 | 19 |

### Table II.

| R.A. | Δα | Δδ | Number of Stars. |
|---|---|---|---|
| h h | s | ″ | |
| 0-1 | +0·020 | −0·56 | 404 |
| 1-2 | ·020 | ·52 | 382 |
| 2-3 | ·042 | ·48 | 411 |
| 3-4 | ·032 | ·35 | 436 |
| 4-5 | ·022 | ·31 | 448 |
| 5-6 | ·051 | ·34 | 526 |
| 6-7 | ·069 | ·21 | 589 |
| 7-8 | ·088 | ·28 | 663 |
| 8-9 | ·065 | ·30 | 680 |
| 9-10 | ·057 | ·42 | 600 |
| 10-11 | ·024 | ·36 | 615 |

| R.A. | Δα | Δδ | Number of Stars. |
|---|---|---|---|
| h h | s | " | |
| 11–12 | ·061 | ·31 | 557 |
| 12–13 | +0·098 | −0·37 | 440 |
| 13–14 | ·076 | ·37 | 491 |
| 14–15 | ·068 | ·29 | 473 |
| 15–16 | ·043 | ·23 | 519 |
| 16–17 | ·053 | ·29 | 528 |
| 17–18 | ·029 | ·33 | 529 |
| 18–19 | ·042 | ·54 | 500 |
| 19–20 | ·028 | ·49 | 385 |
| 20–21 | ·027 | ·59 | 403 |
| 21–22 | ·016 | ·66 | 381 |
| 22–23 | ·028 | ·68 | 381 |
| 23–24 | +0·025 | −0·61 | 411 |
| 0–24 | +0·047 | −0·40 | 11752 |

TABLE III.

| N.P.D. | Δα | Δα sin N.P.D. | Δδ | Number of Stars. |
|---|---|---|---|---|
| ° ° | s | s | " | |
| 90–100 | +0·028 | +0·028 | −0·73 | 301 |
| 100–110 | ·038 | ·037 | ·70 | 210 |
| 110–115 | ·044 | ·041 | ·17 | 428 |
| 115–120 | ·051 | ·045 | ·19 | 1072 |
| 120–125 | ·077 | ·065 | ·43 | 1114 |
| 125–130 | ·058 | ·046 | ·20 | 1199 |
| 130–135 | ·064 | ·047 | ·17 | 1197 |
| 135–140 | ·097 | ·066 | ·49 | 1156 |
| 140–145 | ·088 | ·054 | ·49 | 1229 |
| 145–150 | ·006 | ·003 | ·54 | 1179 |
| 150–155 | ·017 | ·008 | ·36 | 880 |
| 155–160 | ·041 | ·016 | ·47 | 586 |
| 160–165 | + ·024 | + ·007 | ·32 | 504 |
| 165–170 | − ·030 | − ·006 | ·97 | 407 |
| 170–180 | −0·113 | −0·010 | −0·47 | 290 |
| 90–180 | +0·047 | +0·036 | −0·40 | 11752 |

| R.A. | Cape, 1880. Δα | Cape, 1880. Δδ | Melbourne, 1870. Δα | Melbourne, 1870. Δδ | Cape, 1860. Δα | Cape, 1860. Δδ | Cape, 1850. Δα | Cape, 1850. Δδ | Cape, 1840. Δα | Cape, 1840. Δδ |
|---|---|---|---|---|---|---|---|---|---|---|
| h | s | ″ | s | ″ | s | ″ | s | ″ | s | ″ |
| 0·0 | −0·024 | −0·19 | +0·009 | +0·04 | +0·016 | −0·12 | +0·031 | −0·07 | +0·097 | −0·44 |
| 1·0 | ·027 | ·14 | + ·001 | − ·02 | + ·012 | ·23 | ·023 | ·14 | ·119 | ·27 |
| 2·0 | ·016 | ·10 | − ·020 | + ·04 | − ·003 | ·35 | ·026 | ·25 | ·126 | ·18 |
| 3·0 | ·010 | − ·02 | ·053 | ·21 | ·019 | − ·17 | + ·011 | ·22 | ·089 | ·17 |
| 4·0 | ·020 | + ·07 | ·065 | ·34 | ·024 | + ·16 | − ·018 | ·19 | + ·021 | ·28 |
| 5·0 | − ·010 | ·07 | − ·027 | ·30 | ·005 | ·26 | ·024 | ·24 | − ·003 | ·48 |
| 6·0 | + ·013 | ·12 | + ·007 | ·18 | ·008 | ·22 | − ·015 | ·22 | ·002 | ·55 |
| 7·0 | ·032 | ·15 | + ·008 | ·10 | ·015 | ·13 | + ·005 | ·18 | + ·007 | ·54 |
| 8·0 | ·030 | ·11 | − ·016 | ·12 | ·012 | + ·03 | + ·005 | ·18 | − ·030 | ·46 |
| 9·0 | + ·014 | ·04 | ·033 | + ·13 | ·014 | − ·03 | − ·008 | ·21 | ·085 | ·29 |
| 10·0 | − ·006 | ·01 | ·041 | − ·09 | ·057 | ·11 | ·028 | ·17 | ·125 | − ·10 |
| 11·0 | − ·004 | ·06 | − ·019 | ·26 | − ·070 | ·16 | ·037 | − ·06 | ·124 | + ·09 |
| 12·0 | + ·033 | ·06 | + ·036 | ·34 | + ·008 | ·27 | ·013 | + ·01 | ·067 | ·19 |
| 13·0 | ·040 | ·03 | ·057 | ·39 | ·052 | ·30 | ·017 | ·06 | ·048 | ·13 |
| 14·0 | ·025 | ·07 | ·048 | ·19 | ·050 | − ·05 | ·047 | ·17 | ·072 | ·32 |
| 15·0 | ·009 | ·14 | ·045 | − ·01 | ·050 | + ·07 | ·049 | ·27 | ·067 | ·60 |
| 16·0 | + ·001 | ·14 | ·043 | + ·01 | + ·041 | ·14 | ·034 | ·30 | ·043 | ·76 |
| 17·0 | − ·006 | + ·09 | + ·023 | + ·01 | − ·002 | ·19 | ·019 | ·27 | ·027 | ·69 |
| 18·0 | ·011 | − ·04 | − ·001 | − ·10 | ·034 | ·14 | − ·007 | ·18 | ·026 | ·44 |
| 19·0 | 0·12 | ·12 | ·012 | ·11 | − ·023 | ·18 | + ·011 | ·13 | ·010 | ·39 |
| 20·0 | ·019 | ·14 | ·017 | ·04 | ·000 | ·20 | ·021 | ·16 | − ·002 | ·42 |
| 21·0 | ·025 | ·23 | − ·006 | ·07 | + ·008 | + ·02 | ·031 | ·12 | + ·010 | + ·39 |
| 22·0 | ·025 | ·27 | + ·007 | − ·07 | ·002 | − ·18 | ·037 | ·11 | ·025 | − ·09 |
| 23·0 | −0·020 | −0·25 | +0·011 | 0·00 | +0·008 | −0·20 | +0·039 | +0·02 | +0·063 | −0·40 |

TABLE V.

| N.P.D. | Cape, 1880. Δα | Cape, 1880. Δδ | Melbourne, 1870. Δα | Melbourne, 1870. Δδ | Cape, 1860. Δα | Cape, 1860. Δδ | Cape, 1850. Δα | Cape, 1850. Δδ | Cape, 1840. Δα | Cape, 1840. Δδ |
|---|---|---|---|---|---|---|---|---|---|---|
| ° | s | ″ | s | ″ | s | ″ | s | ″ | s | ′ |
| 95 | +0·028 | −0·73 | +0·023 | −0·57 | +0·034 | −0·82 | +0·015 | −0·19 | −0·008 | −0·73 |
| 100 | ·032 | ·71 | ·018 | ·36 | ·028 | ·58 | ·011 | ·28 | ·018 | ·53 |
| 105 | ·038 | ·70 | ·013 | − ·21 | ·012 | ·46 | + ·006 | − ·35 | ·015 | − ·16 |
| 110 | ·041 | ·37 | ·004 | + ·07 | ·003 | ·30 | − ·007 | + ·17 | ·011 | + ·37 |
| 115 | ·048 | ·19 | ·010 | + ·11 | ·015 | ·40 | ·022 | ·37 | ·011 | ·41 |
| 120 | ·064 | ·32 | ·028 | − ·13 | ·040 | ·65 | ·027 | + ·07 | ·007 | ·11 |
| 125 | ·065 | ·32 | ·040 | − ·17 | ·063 | ·60 | ·048 | − ·12 | ·016 | ·07 |
| 130 | ·060 | ·20 | ·046 | + ·10 | ·080 | ·37 | ·074 | − ·07 | ·027 | ·30 |
| 135 | ·078 | ·32 | ·052 | ·18 | ·098 | ·43 | ·071 | + ·01 | ·010 | ·46 |
| 140 | ·088 | ·50 | ·055 | ·02 | ·118 | ·63 | ·073 | ·04 | − ·006 | ·48 |
| 145 | ·048 | ·53 | ·035 | ·01 | ·103 | ·67 | ·055 | ·16 | + ·012 | ·78 |
| 150 | ·010 | ·47 | ·005 | ·17 | ·064 | ·53 | ·068 | + ·08 | ·000 | ·92 |
| 155 | ·029 | ·42 | + ·005 | ·31 | ·067 | ·32 | ·031 | − ·04 | + ·047 | ·81 |
| 160 | + ·032 | ·44 | − ·037 | ·40 | + ·013 | ·15 | ·010 | ·00 | +0·083 | + ·44 |
| 165 | − ·007 | ·80 | ·090 | + ·13 | −0·078 | −0·33 | −0·032 | − ·23 | — | − ·31 |
| 170 | ·058 | ·83 | ·125 | ·00 | — | — | — | −0·09 | — | −0·19 |
| 175 | −0·113 | −0·47 | −0·176 | +0·13 | — | — | — | — | — | — |

*Blackheath : Jun · 1887.*

*A Catalogue of 480 Stars to be used as Fundamental Stars for Observations of Zones between 20° and 80° South Declination.* By Prof. A. Auwers.

One of the most important works to be done by the next generation of astronomers will consist in a new and systematic determination of the places of the southern fixed stars down to the 9th magnitude.

One object of this determination will be the completion of the general knowledge of stellar proper motions by comparisons to be made with Dr. Gould's determinations for the epoch 1875. If this alone were considered, the new observations might advantageously be deferred some ten or twenty years more. But the wants of the great photographic survey, to be made according to the Paris programme with a mean epoch of probably 1900±, will render it preferable to have this new determination made nearly for this same epoch.

The most efficient way to secure homogeneousness and completeness in this determination will be the arrangement of zone-observations like those of the Astronomische Gesellschaft, till now made between the declinations 80° and −2°, and presently to be extended to −23°, constructing the working lists for the zones from the preliminary photographic survey of the southern heavens by which Dr. Gill has undertaken to complete the Bonner Durchmusterung. Astronomers hope to have the results of this survey within the next few years, and in order to enable the southern observatories then not only to begin the zone-observations without delay, but also to make the reductions within due time, it appears not too early to prepare for these observations of southern zones by providing at once for a uniform and accurate determination of the positions of a sufficient number of stars, which ought to be used as fundamental stars in the reduction of the zones.

Dr. Gill having expressed to me his desire that I should make the selection of these stars, in order that they should be included in the new working list which was to be constructed about a year ago for the Transit circle of the Cape Observatory, I have drawn up the following list, which I now beg herewith to communicate to the astronomers of the southern hemisphere, expressing, in accordance with Dr. Gill, the wish that a sufficient number of them will co-operate towards the accurate determination of these stars in the same manner as has been done for the fundamental stars used in the zone-observations of the Astronomische Gesellschaft.

The selection of the stars included in the following catalogue was to be made upon the following principles :—

1. The stars ought to be distributed, at convenient intervals, as equally as possible over the area covered by the zones to be observed. This area may be considered to be conveniently

filled with fundamental stars, if in each single zone comprising 10° of declination these stars follow each other on the average within $15^m$ to $20^m$ in the lower declinations, and $20^m$ to $25^m$ in the higher.

2. The stars ought to be of such a kind as will afford the most complete guaranty for accurate and accordant observation by different observers. The following stars should be avoided:—first, very bright stars, with whose observations rather large personalities are known occasionally to interfere; and second, double stars in which the companion might disturb the observation of the principal star, or possibly prevent its being referred by different observers to exactly the same point.

3. Where there is any choice no star ought to be admitted unless it be sufficiently observed in previous catalogues to allow of a determination of its proper motion, with an accuracy sufficient to allow the new position to be brought forward ten or fifteen years without diminishing its accuracy to an extent which would become appreciable in the reduction of the zone-observations.

The most elegant solution of the problem with respect to condition 1, and apparently also to condition 2, might have been attained by the exclusive use of the stars of one or two middle orders of magnitude, the stars of about 6 mag. and 7 mag., as fundamental stars for the zones. The number of these stars is sufficiently great in all regions to allow of a very uniform distribution of the fundamental points throughout, and, at the same time, the stars of 6 mag. and 7 mag. most probably are those objects which with the present meridian instruments are observed with the highest degree of precision in the single observation and with the least amount of systematic difference between different observers. But in the latter respect the apparent gain to be obtained by their use would be quite illusory, because the places of these stars themselves must be determined by referring them to the brighter stars, so that it remains impossible to get rid of any kind of personality to which the observations of brighter stars are liable. On the other hand, with the stars of 6 mag. and 7 mag., condition 3 could be fulfilled only in such an incomplete and unsatisfactory manner that their choice could not be recommended. The sacrifice of uniformity of distribution unavoidably connected with the choice of the stars of brighter magnitudes than the 6th, because of their varying frequency and comparatively small number, is really much the lesser evil.

Having, by condition 1, fixed the extent of the catalogue at a number of stars between 400 and 500, I have for the above reasons chosen those stars to form its main body whose magnitude, according to Gould's Uranometry, ranges between the limits 2·0 and 5·0. The limits of the zones, for which the fundamental stars were to be selected, were determined by the southern limit of the zones of the Astronomische Gesellschaft and the northern limit of the special circumpolar work already under-

taken by the Cape Observatory, and therefore will be $-23°$ and $-80°$ declination. For the fundamental catalogue I have extended the northern limit to $-20°$, but generally retained the southern limit of $-80°$, because it does not seem desirable to combine the presently proposed observations with those of a greater number of stars within ten degrees of the South Pole. The latter work may be better made the object of other specially conducted observations besides those of the Cape Observatory already mentioned.

The Uranometria Argentina contains between declinations $-20°$ and $-80°$ (for the Equinox 1875) 380 stars not brighter than 2·0 mag. and not fainter than 5·0 mag., which are without companions such as might interfere with the accurate and uniform observation of the principal star, one or two variable stars, however, being included in this number, which during a part of their period fall somewhat below 5 mag. The exclusion of double stars has been adhered to with still greater rigidity than in the construction of the fundamental list for the southern zones ($-2°$ to $-23°$) of the Astronomische Gesellschaft; even the stars with very faint or distant companions have been excluded with rare exceptions. For even where such companions cannot, by their faintness or their relative position, influence in any degree the proper estimate of the point to be observed, or of its correct position with respect to the wires, an observer—and more possibly a good observer—is liable to be troubled to a certain extent by their mere existence, as they are apt to detract, for a moment, part of the attention from what ought to constitute during the transit of a fundamental star the exclusive object of the full attention of the astronomer observing a zone—viz. that he shall fix, with the greatest possible accuracy, a point to which to refer the zone under observation. Only in some very few cases I have retained some of those known double stars, in which the possibility of a disturbing influence appears limited to a very small extent—wholly excluded in one case—viz. four objects (to which afterwards $\epsilon$ *Canis maj.* has been added as a fifth) already occurring in the Fundamental Catalogue of the Berliner Jahrbuch, and five more, which could not easily be superseded for want of other stars in the same region. Possibly some more objects of this kind will be found in the catalogue when the stars of the southern heavens have been examined more closely with regard to their duplicity than has yet been done, or reported to have been done.

Out of the 380 stars accordingly available, including the nine known double stars, it was not possible to retain for the catalogue more than 280. The remaining 100 were excluded, part of them being wholly superfluous in regions covered densely enough without them; part of them because their transits would take place so nearly at the same time with those of *several* other stars in remoter declinations that, by retaining them, the time necessary for complete observation of the catalogue would have been

disproportionally extended. The majority of these excluded stars is contained in the hours 6 to 9 and 12 to 15 of Right Ascension, in which the brighter stars are most densely crowded together in the southern heavens. To replace these stars in more convenient positions, where it appeared at all necessary to replace them, and to fill up the greater gaps, chiefly in the hours 19 to 2, between the brighter stars, I had recourse to the stars noted 5·1 mag. to 6·0 mag. in the Uranometria Argentina, in some cases, for want of such stars, to still fainter ones, adding in this manner 193 stars between the limits −20° and −80°, sixteen of which are of the magnitude 6–7, and the four faintest of the magnitude 7–6; finally, two stars somewhat exceeding the upper limit of brightness (*ε Canis maj.* and *β Crucis*) were added, and, besides, five stars situated a little beyond the southern limit of −80°, in regions which could not be provided for sufficiently without them.

The catalogue accordingly contains 480 stars, which are distributed for the Equinox 1875 as follows:—

| Hour | contains | Hour | contains | Hour | contains |
|---|---|---|---|---|---|
| 0 | 19 stars | 8 | 17 stars | 16 | 23 stars |
| 1 | 19 " | 9 | 19 " | 17 | 23 " |
| 2 | 18 " | 10 | 19 " | 18 | 25 " |
| 3 | 19 " | 11 | 19 " | 19 | 21 " |
| 4 | 15 " | 12 | 21 " | 20 | 19 " |
| 5 | 22 " | 13 | 20 " | 21 | 18 " |
| 6 | 19 " | 14 | 19 " | 22 | 26 " |
| 7 | 21 " | 15 | 16 " | 23 | 23 " |

| | | | | | |
|---|---|---|---|---|---|
| Zone | −20° | to | −30° | contains | 99 stars |
| " | −30 | " | −40 | " | 85 " |
| " | −40 | " | −50 | " | 89 " |
| " | −50 | " | −60 | " | 77 " |
| " | −60 | " | −70 | " | 70 " |
| " | −70 | " | −80 | " | 54 " |
| " | −80 | " | −82·5 | " | 6 " |

This distribution may be considered to be sufficiently uniform, and cannot be rendered more uniform, if conditions 2 and 3 remain fulfilled with equal approximation throughout. It has not been possible, with the available material, to reach the average number of twenty stars in each single hour of Right Ascension, while in some hours it was possible somewhat to exceed this number without interfering with an equable facility of getting through the catalogue in the observations to be made for the determination of the fundamental positions. The selection of the stars has been assisted throughout by laying down their positions, and those of a good many other stars of 5 mag. and 6 mag., besides those finally selected, in a map drawn upon a large

scale, carefully scrutinising in every single instance what combination would afford the greatest advantage in the observations and the reduction of the zones. As to the determination of the fundamental stars, care was taken that, assuming five minutes to be required for a complete observation with a transit circle, in no Right Ascension should more stars interfere with each other than would allow of the whole catalogue being gone through $n$ times completely in $4n$ observing nights. This scrutiny, however, was made with the catalogue drawn up for the year 1875, and has not been repeated with the Right Ascensions as finally brought forward to the epoch 1900.

In what degree it has been found possible to adhere to condition 3, regarding the means for determining the proper motions, may be inferred from the following statement. Of the 480 stars there occur—

| | |
|---|---|
| In the Catalogue of Lacaille (princ. st.) ... | 133 |
| " " Bradley... ... ... | 84 |
| " " Piazzi ... ... ... | 221 |
| " " Johnson (St. Helena)... | 252 |
| " Cape Catalogue for 1840 ... ... | 410 |
| " " " 1850 ... ... | 452 |
| " " " 1860 ... ... | 248 |
| " " " 1880 ... ... | 468 |
| " Williamstown Catalogue ... ... | 127 |
| " First Melbourne Catalogue ... ... | 244 |

all of them, of course, being included in Gould's Catalogue (Catalogo General Argentino).

Five stars were inserted into the catalogue which are not contained in any previous catalogue except Gould's (three of them, however, forming part of the list of fundamental stars recently determined for the southern zones of the Astronomische Gesellschaft), and four others, which besides in this catalogue occur either in Stone's Catalogue, 1880, or in the Melbourne Catalogue. Two stars have been observed, previously to Gould and Stone 1880, only by Piazzi. Further, fourteen stars do not occur previously to the Cape Catalogue for 1850 (except Taylor's Catalogue, which contains some of them, but scarcely affords positions fit for determining proper motions), and the Cape 1850 Catalogue gives only one co-ordinate for three of these stars. Altogether, therefore, for twenty-five stars condition 3 is only very unsatisfactorily fulfilled; but in all these cases it proved to be impossible to replace the stars at convenient places by other stars already better determined.

The magnitudes are given in the following catalogue according to the determinations in the Uranometria Argentina. The designation of the stars is, for the great majority of them, likewise that of the same work. In those constellations,

however, which are visible in middle Europe completely, or at least to a predominant part of their full extent, and which are comprised so far in the uranometrical researches of Bayer and Argelander, or in Flamsteed's catalogue work, Bayer-Argelander's nomenclature and Flamsteed's numbering, together with limits of the constellations drawn accordingly, ought to be retained, in my opinion, without any alterations (except those, of course, which are necessary to correct for accidental errors). From those constellations, small parts of which only can be seen in middle Europe and are investigated by Bayer and his European successors, *Argo*, *Centaurus*, *Lupus*, *Corona Australis*, Bayer's letters ought to be withdrawn, being only apt to interfere with the correct extension of his own principle of lettering over the whole constellation. In *Argo*, however, I do not agree with Gould completely. It seems to me impossible to supersede designations so thoroughly connected with the history of astronomy as *α Argus* or *η Argus* by other designations, and I consider it necessary, therefore, to retain the name of the entire constellation *Argo* in the designation of its brighter stars. The limit for distinguishing between this entire constellation and its separate parts will be drawn in the most simple way, if all the stars designated with Lacaille's Greek letters are counted through *Argo*, and the subdivisions *Carina*, *Puppis*, and *Vela* are introduced only to distinguish between the smaller stars designated by a threefold repetition of the Latin alphabet. According to this principle the names are set down in the catalogue, with one more trifling deviation from the Uranometria Argentina. In this work two stars in *Puppis* are lettered I and J, a similarity of designation too much apt to produce confusion, and better therefore to be avoided. I have suppressed the symbol J and inserted the star which has it appended in the Uranometria Argentina simply as *Puppis* 218 Gould.

The last column contains some remarks to note the few double stars, and to call the attention to neighbouring stars in such cases when they might give rise to mistakes. Those remarks would not appear to be needed in the determination of the positions of the stars of the catalogue with meridian instruments; but it might be inferred from experience that they will prove to be useful in the zone-observations themselves or in some other use of the present catalogue—for example, in field-work.

*Catalogue.*

| No. | Name. | Mag. | R.A. 1900. | Ann. var. | Decl. 1900. | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|
| | | | h m s | s | ° ′ | ′ | |
| 1 | ε Phœnicis | 4 | 0 4 20 | +3·1 | −46 17·9 | +0·33 | |
| 2 | κ² Sculptoris | 5–6 | 6 30 | 3·0 | 28 21·4 | 0·33 | |
| 3 | θ Sculptoris | 5–6 | 6 38 | 3·0 | 35 41·7 | 0·33 | |
| 4 | ζ Tucanæ | 4 | 14 51 | +3·2 | 65 27·8 | +0·35 | |

| Name. | Mag. | R.A. 1900. | Ann. var. | Decl. 1900. | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|
| | | h m s | s | ° ′ | ′ | |
| Hydri | 3-2 | 0 20 30 | +3·3 | −77 49·1 | +0·34 | |
| Phœnicis | 2-3 | 21 19 | 2·9 | 42 50·9 | 0·33 | |
| eti, 49 G. | 5-6 | 25 23 | 3·0 | 24 20·4 | 0·33 | |
| $^{1}$ Phœnicis | 5-4 | 26 35 | 2·9 | 49 21·4 | 0·33 | |
| :ulptoris, 77 G. | 6 | 28 44 | 3·0 | 30 6·6 | 0·33 | |
| hœnicis, 58 G. | 6-5 | 29 43 | 2·9 | 52 55·5 | 0.33 | |
| eti, 59 G. | 6 | 32 12 | 3·1 | 25 19·1 | 0·33 | |
| Phœnicis | 5-4 | 36 36 | 2·8 | 46 38·0 | 0·33 | |
| Phœnicis | 4-5 | 38 52 | 2·7 | 58 0·7 | 0·33 | |
| $^{2}$ Sculptoris | 6 | 39 21 | 2·9 | 38 58·4 | 0·33 | |
| eti, 73 G. | 5-6 | 39 47 | 3·0 | 22 33·4 | 0·33 | |
| Hydri | 6-5 | 45 7 | 2·1 | 75 28·0 | 0·33 | |
| $^{2}$ Tucanæ | 5-6 | 51 16 | 2·3 | 70 4·0 | 0·33 | |
| Sculptoris | 4 | 53 47 | 2·9 | 29 53·9 | 0·32 | |
| 'hœnicis, 80 G. | 6-7 | 57 48 | 2·5 | 57 32·4 | 0·32 | |
| Phœnicis | 3-4 | 1 1 37 | 2·7 | 47 15·3 | 0·32 | |
| Tucanæ | 6-5 | 3 20 | 2·4 | 62 18·6 | 0·32 | |
| culptoris, 102 G. | 6 | 8 9 | 2·8 | 38 23·2 | 0·32 | |
| culptoris, 109 G. | 6 | 18 52 | 2·8 | 31 27·9 | 0·31 | |
| [ydri, 9 G. | 6-7 | 21 38 | 2·1 | 64 53·4 | 0.31 | |
| Phœnicis | 3-4 | 24 1 | 2·6 | 43 49·8 | 0·31 | |
| 8 Ceti | 5-6 | 24 48 | 2·9 | 22 8·8 | 0·31 | |
| Phœnicis | 4 | 27 5 | 2·5 | 49 35·7 | 0·31 | |
| [ydri, 14 G. | 6-7 | 32 59 | 0·3 | 79 0·7 | 0·30 | |
| culptoris, 129 G. | 6 | 37 38 | 2·6 | 37 20·2 | 0·30 | |
| Sculptoris | 5 | 40 57 | +2·8 | 25 33·1 | 0·30 | 9 mag. 5″ |
| $^{1}$ Hydri | 6-7 | 41 16 | −0·1 | 79 39·2 | 0·30 | |
| $^{2}$ Eridani | 5-6 | 42 17 | +2·3 | 54 1·6 | 0·30 | |
| Phœnicis | 5 | 49 38 | 2·4 | 46 47·6 | 0·29 | |
| Eridani | 4 | 52 4 | 2·3 | 52 6·4 | 0·30 | |
| $^{2}$ Hydri | 5 | 52 24 | 1·5 | 68 8·4 | 0·30 | |
| 9 υ Ceti | 4 | 55 17 | 2·8 | 21 33·7 | 0·29 | |
| Hydri | 3 | 55 37 | 1·9 | 62 3·4 | 0·29 | |
| Fornacis | 5 | 2 0 0 | 2·7 | 29 46·6 | 0·29 | |
| Fornacis | 5 | 8 30 | 2·6 | 31 11·5 | 0·28 | |
| 'hœnicis, 135 G. | 6 | 10 29 | 2·4 | 41 37·9 | 0·28 | |
| Eridani | 3-4 | 12 55 | 2·1 | 51 58·5 | 0·28 | |
| Fornacis | 5 | 17 57 | +2·7 | 24 16·2 | +0·28 | |

| No. | Name. | Mag. | R.A. 1900. | Ann. var. | Decl. 1900. | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|
| | | | h m s | s | ° ′ | ′ | |
| 43 | δ Hydri | 4 | 2 19 58 | +1·1 | −69 6·9 | +0·27 | |
| 44 | λ Horologii | 6 | 22 6 | 1·7 | 60 45·5 | 0·27 | |
| 45 | κ Hydri | 6 | 22 16 | 0·3 | 74 5·9 | 0·27 | |
| 46 | κ Eridani | 4 | 23 19 | 2·2 | 48 10·1 | 0·27 | |
| 47 | λ¹ Fornacis | 6 | 28 56 | +2·5 | 35 5·3 | 0·27 | |
| 48 | μ Hydri | 6–5 | 33 46 | −1·5 | 79 32·7 | 0·26 | |
| 49 | η Horologii | 6–5 | 34 6 | +2·0 | 52 58·6 | 0·26 | |
| 50 | ι Eridani | 4 | 36 43 | 2·4 | 40 17·0 | 0·26 | |
| 51 | ε Hydri | 4 | 38 2 | 0·9 | 68 41·8 | 0·26 | |
| 52 | β Fornacis | 4–5 | 44 55 | 2·5 | 32 49·6 | 0·25 | |
| 53 | 2 τ² Eridani | 5–4 | 46 30 | 2·7 | 21 25·0 | 0·25 | |
| 54 | β Horologii | 5 | 56 54 | 1·1 | 64 28·1 | 0·24 | |
| 55 | 11 τ³ Eridani | 4 | 57 59 | 2·6 | 24 0·9 | 0·24 | |
| 56 | Eridani, 58 G. | 6–7 | 59 31 | 2·0 | 47 22·0 | 0·24 | |
| 57 | μ Horologii | 5–6 | 3 1 15 | 1·4 | 60 7·5 | 0·23 | |
| 58 | θ Hydri | 6 | 2 3 | 0·1 | 72 17·6 | 0·23 | |
| 59 | 12 Eridani | 3–4 | 7 48 | 2·5 | 29 22·9 | 0·24 | 7–8 mag. 9″ |
| 60 | Horologii, 38 G. | 6–7 | 10 1 | 1·5 | 57 41·7 | 0·23 | |
| 61 | Fornacis, 79 G. | 7–6 | 10 44 | 2·4 | 35 55·8 | 0·23 | |
| 62 | e Eridani | 4–5 | 15 55 | +2·4 | 43 27·1 | 0·23 | |
| 63 | ι Hydri | 6 | 18 26 | −1·6 | 77 45·2 | 0·22 | |
| 64 | κ Reticuli | 5 | 27 36 | +1·0 | 63 17·5 | 0·21 | |
| 65 | 19 τ⁵ Eridani | 4 | 29 22 | 2·6 | 21 58·1 | 0·20 | |
| 66 | Horologii, 45 G. | 6 | 29 35 | 1·8 | 50 43·1 | 0·20 | |
| 67 | y Eridani | 5 | 33 30 | 2·1 | 40 36·1 | 0·20 | |
| 68 | δ Fornacis | 5 | 38 16 | 2·4 | 32 15·4 | 0·19 | |
| 69 | 27 τ⁶ Eridani | 4 | 42 32 | 2·6 | 23 32·7 | 0·18 | |
| 70 | β Reticuli | 4 | 42 56 | 0·7 | 65 7·3 | 0·19 | |
| 71 | g Eridani | 4 | 45 43 | +2·2 | 36 30·2 | 0·18 | |
| 72 | γ Hydri | 3 | 48 47 | −1·0 | 74 32·7 | 0·18 | |
| 73 | Doradus, 1 G. | 7–6 | 51 56 | +1·6 | 52 58·9 | 0·18 | |
| 74 | 36 τ⁹ Eridani | 4 | 55 40 | 2·5 | 24 18·0 | 0·17 | |
| 75 | δ Reticuli | 5–4 | 57 9 | 0·9 | 61 41·0 | 0·17 | |
| 76 | Eridani, 174 G. | 6 | 4 1 29 | 2·5 | 27 55·7 | 0·17 | |
| 77 | α Horologii | 4 | 10 41 | 2·0 | 42 32·5 | 0·15 | |
| 78 | α Reticuli | 3–4 | 13 8 | 0·8 | 62 43·4 | 0·15 | |
| 79 | γ Doradus | 4–5 | 13 24 | 1·6 | 51 44·4 | 0·15 | |
| 80 | Eridani, 212 G. | 5–6 | 16 17 | +2·6 | 20 52·7 | +0·15 | |

| No. | Name. | Mag. | R.A. 1900. | | | Ann. var. | Decl. 1900. | | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h | m | s | s | ° | ′ | ′ | |
| 81 | 43 *d* Eridani | 4 | 4 | 20 | 16 | +2·2 | −34 | 15·0 | +0·14 | |
| 82 | η Reticuli | 6 | | 20 | 47 | +0·6 | 63 | 37·5 | 0·14 | |
| 83 | δ Mensæ | 6 | | 24 | 43 | −4·2 | 80 | 27·0 | 0·13 | |
| 84 | δ Cæli | 5 | | 27 | 47 | +1·8 | 45 | 10·1 | 0·13 | |
| 85 | 52 $\upsilon^2$ Eridani | 4–3 | | 31 | 40 | 2·3 | 30 | 46·0 | 0·13 | |
| 86 | α Doradus | 3 | | 31 | 50 | 1·3 | 55 | 15·1 | 0·13 | |
| 87 | Eridani, 258 G. | 6 | | 35 | 57 | 2·5 | 24 | 40·7 | 0·12 | |
| 88 | α Cæli | 5–4 | | 37 | 20 | 1·9 | 42 | 3·3 | 0·12 | |
| 89 | κ Doradus | 6–5 | | 42 | 50 | +0·9 | 59 | 55·0 | 0·11 | |
| 90 | μ Mensæ | 6–5 | | 44 | 3 | −0·6 | 71 | 6·9 | 0·11 | |
| 91 | 2 ε Leporis | 3–4 | 5 | 1 | 13 | +2·5 | 22 | 30·3 | 0·08 | |
| 92 | $\eta^2$ Pictoris | 5–6 | | 2 | 22 | 1·5 | 49 | 42·8 | 0·08 | |
| 93 | ζ Doradus | 5 | | 3 | 48 | +1·0 | 57 | 36·7 | 0·07 | |
| 94 | β Mensæ | 6–5 | | 4 | 19 | −0·8 | 71 | 27·1 | 0·08 | |
| 95 | ξ Mensæ | 6 | | 10 | 14 | −7·0 | 82 | 36·3 | 0·07 | |
| 96 | θ Doradus | 5 | | 13 | 50 | −0·1 | 67 | 17·8 | 0·07 | |
| 97 | ο Columbæ | 5 | | 13 | 51 | +2·1 | 34 | 59·4 | 0·07 | |
| 98 | Columbæ, 12 G. | 6 | | 15 | 26 | 2·4 | 27 | 28·3 | 0·06 | |
| 99 | ζ Pictoris | 6 | | 16 | 55 | 1·5 | 50 | 42·9 | 0·06 | |
| 100 | Columbæ, 18 G. | 6 | | 23 | 53 | 1·9 | 41 | 1·3 | 0·05 | |
| 101 | Pictoris, 20 G. | 6–5 | | 27 | 24 | 1·6 | 47 | 9·0 | 0·04 | |
| 102 | ε Columbæ | 4 | | 27 | 39 | 2·1 | 35 | 32·6 | 0·05 | |
| 103 | β Doradus | 4 | | 32 | 46 | +0·5 | 62 | 33·3 | 0·04 | |
| 104 | γ Mensæ | 6–5 | | 35 | 50 | −2·4 | 76 | 24·9 | 0·03 | |
| 105 | α Columbæ | 2–3 | | 36 | 1 | +2·2 | 34 | 7·6 | 0·03 | |
| 106 | 13 γ Leporis | 4 | | 40 | 18 | 2·5 | 22 | 28·7 | 0·03 | 7–8 mag. pr.1ˢ b.1′·6 |
| 107 | δ Doradus | 4–5 | | 44 | 35 | 0·1 | 65 | 46·4 | 0·02 | |
| 108 | 15 δ Leporis | 4 | | 47 | 0 | 2·6 | 20 | 53·1 | 0·01 | |
| 109 | β Columbæ | 3 | | 47 | 26 | 2·1 | 35 | 48·4 | 0·03 | |
| 110 | γ Pictoris | 5–4 | | 48 | 0 | 1·1 | 56 | 11·5 | 0·02 | |
| 111 | η Columbæ | 4 | | 56 | 5 | +1·8 | 42 | 49·2 | +0·01 | |
| 112 | κ Mensæ | 6 | | 57 | 2 | −4·1 | 79 | 22·8 | 0·00 | |
| 113 | Puppis, 1 G. | 6 | 6 | 1 | 36 | +1·7 | 45 | 2·2 | 0·00 | 6–7 mag. seq.12ˢ a.2′·5 |
| 114 | Columbæ, 74 G. | 6 | | 2 | 15 | 2·3 | 29 | 44·8 | 0·00 | |
| 115 | Pictoris, 47 G. | 6–5 | | 6 | 8 | 0·5 | 62 | 8·1 | −0·01 | |
| 116 | δ Pictoris | 5 | | 8 | 21 | 1·2 | 54 | 56·8 | 0·01 | |
| 117 | κ Columbæ | 5 | | 12 | 59 | +2·1 | 35 | 6·4 | 0·02 | |
| 118 | α Mensæ | 5–6 | | 13 | 13 | −1·8 | 74 | 43·0 | −0·02 | |

| No. | Name. | Mag. | R.A. 1900. | Ann. var. | Decl. 1900. | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|
| | | | h m s | s | ° ′ | ′ | |
| 119 | 1 ζ Canis maj. | 3 | 6 16 28 | +2·3 | −30 1·2 | −0·02 | |
| 120 | λ Canis maj. | 6-5 | 24 27 | +2·2 | 32 31·0 | 0·03 | |
| 121 | $\pi^2$ Doradus | 6 | 26 20 | −0·5 | 69 38·0 | 0·04 | |
| 122 | 5 $\xi^2$ Canis maj. | 5 | 30 52 | +2·5 | 22 53·1 | 0·04 | |
| 123 | N Carinæ | 5 | 32 46 | 1·3 | 52 53·5 | 0·05 | |
| 124 | ν Argus | 3-4 | 34 42 | 1·8 | 43 6·4 | 0·05 | |
| 125 | 13 κ Canis maj. | 4 | 46 6 | 2·2 | 32 23·5 | 0·06 | |
| 126 | α Pictoris | 3-4 | 47 10 | 0·6 | 61 50·1 | 0·06 | |
| 127 | τ Argus | 3 | 47 27 | +1·5 | 50 29·7 | 0·07 | |
| 128 | ζ Mensæ | 6 | 48 23 | −4·9 | 80 42·5 | 0·07 | |
| 129 | ι Volantis | 6-5 | 52 35 | −0·7 | 70 50·3 | 0·08 | |
| 130 | Canis maj., 105 G. | 6 | 54 30 | +2·5 | 25 16·8 | 0·08 | |
| 131 | ε Canis maj. | 2-1 | 54 42 | 2·4 | 28 50·1 | 0·08 | 10–11 mag. [illegible] |
| 132 | Carinæ, 27 G. | 6-5 | 7 2 26 | +1·1 | 56 35·8 | 0·09 | |
| 133 | θ Mensæ | 6-5 | 2 55 | −3·7 | 79 16·6 | 0·09 | |
| 134 | 25 δ Canis maj. | 2 | 4 20 | +2·4 | 26 14·0 | 0·09 | |
| 135 | *I* Puppis | 5 | 9 43 | 1·7 | 46 35·6 | 0·10 | |
| 136 | π Argus | 3-2 | 13 37 | 2·1 | 36 55·1 | 0·10 | |
| 137 | 29 Canis maj. | 5-6 | 14 30 | 2·5 | 24 22·5 | 0·10 | |
| 138 | δ Volantis | 4 | 16 53 | 0·0 | 67 46·4 | 0·11 | |
| 139 | 31 η Canis maj. | 3-2 | 20 8 | 2·4 | 29 6·4 | 0·11 | |
| 140 | Puppis, 108 G. | 5-6 | 29 46 | 2·6 | 22 4·8 | 0·13 | |
| 141 | *Q* Carinæ | 5-6 | 33 11 | 1·5 | 52 18·6 | 0·13 | |
| 142 | *f* Puppis | 5 | 33 40 | 2·2 | 34 44·6 | 0·13 | |
| 143 | *l* Puppis | 4-5 | 39 47 | 2·4 | 28 42·9 | 0·14 | |
| 144 | *c* Puppis | 4-3 | 41 41 | +2·1 | 37 43·5 | 0·14 | |
| 145 | ζ Volantis | 4-5 | 43 4 | −0·7 | 72 21·9 | 0·14 | |
| 146 | 7 ξ Argus | 4-3 | 45 5 | +2·5 | 24 36·5 | 0·15 | |
| 147 | *P* Puppis | 4-5 | 46 12 | 1·8 | 46 7·2 | 0·15 | |
| 148 | *a* Puppis | 4 | 48 46 | 2·1 | 40 19·1 | 0·15 | |
| 149 | Volantis, 19 G. | 6 | 49 1 | 0·4 | 65 56·4 | 0·15 | |
| 150 | Puppis, 218 G. | 4-5 | 50 22 | 1·8 | 47 50·5 | 0·15 | |
| 151 | χ Argus | 4-3 | 54 14 | 1·5 | 52 42·8 | 0·16 | |
| 152 | ζ Argus | 2-3 | 8 0 5 | 2·1 | 39 43·3 | 0·17 | |
| 153 | ρ Argus | 3 | 3 17 | 2·5 | 24 0·9 | 0·17 | |
| 154 | γ Argus | 3 | 6 27 | 1·8 | 47 2·5 | 0·17 | |
| 155 | *q* Puppis | 5-4 | 14 49 | 2·2 | 36 21·0 | 0·18 | |
| 156 | ε Argus | 2 | 20 28 | +1·2 | 59 11·3 | −0·19 | |

| Name. | Mag. | R.A. 1900. | | | Ann. var. | Decl. 1900. | | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | h | m | s | s | ° | ′ | ′ | |
| ı Chamæleontis | 5-4 | 8 | 23 | 39 | −1·7 | −77 | 9·7 | −0·20 | |
| ȝ Volantis | 4 | | 24 | 39 | +0·7 | 65 | 48·1 | 0·20 | |
| ' Velorum | 5-4 | | 34 | 8 | 2·1 | 42 | 38·4 | 0·21 | |
| ?yxidis, 19 G. | 6-5 | | 34 | 46 | 2·6 | 22 | 19·4 | 0·21 | |
| ȝ Pyxidis | 4-5 | | 36 | 12 | 2·3 | 34 | 57·1 | 0·21 | |
| ! Carinæ | 5-4 | | 38 | 24 | 1·3 | 59 | 24·2 | 0·21 | |
| . Pyxidis | 4 | | 39 | 34 | 2·4 | 32 | 49·5 | 0·21 | |
| Argus | 2 | | 41 | 56 | 1·7 | 54 | 20·5 | 0·22 | |
| Velorum | 4 | | 42 | 38 | +2·0 | 45 | 40·5 | 0·22 | |
| Chamæleontis | 6-5 | | 44 | 44 | −1·9 | 78 | 36·0 | 0·22 | |
| ' Pyxidis | 4-5 | | 46 | 18 | +2·5 | 27 | 20·3 | 0·22 | |
| Carinæ | 4 | | 52 | 47 | 1·4 | 60 | 15·8 | 0·23 | |
| Velorum | 5-4 | 9 | 0 | 42 | 2·1 | 46 | 41·9 | 0·24 | |
| Volantis | 4 | | 0 | 52 | 1·0 | 65 | 59·7 | 0·24 | |
| Argus | 2-3 | | 4 | 19 | 2·2 | 43 | 1·7 | 0·24 | |
| r Carinæ | 5 | | 4 | 53 | 0·2 | 72 | 12·0 | 0·24 | |
| Argus | 2 | | 12 | 6 | 0·7 | 69 | 18·3 | 0·25 | |
| Argus | 2-3 | | 14 | 25 | 1·6 | 58 | 51·3 | 0·25 | |
| Pyxidis | 5-6 | | 17 | 4 | 2·6 | 25 | 32·4 | 0·25 | |
| Argus | 3-2 | | 19 | 1 | 1·9 | 54 | 35·0 | 0·25 | |
| Antliæ | 5 | | 25 | 7 | 2·5 | 35 | 30·8 | 0·26 | |
| Argus | 4-3 | | 26 | 46 | 2·4 | 40 | 1·7 | 0·26 | |
| [ydræ, 160 G. | 6 | | 28 | 36 | 2·8 | 20 | 40·4 | 0·26 | |
| l Carinæ | 6 | | 30 | 51 | 0·5 | 72 | 38·2 | 0·26 | |
| Carinæ | 5 | | 31 | 32 | 1·7 | 58 | 47·1 | 0·27 | |
| f Velorum | 5 | | 33 | 15 | 2·1 | 48 | 54·4 | 0·27 | |
| Antliæ | 5 | | 39 | 45 | 2·7 | 27 | 18·7 | 0·27 | |
| Carinæ | 4-5 | | 42 | 30 | 1·6 | 62 | 2·8 | 0·27 | |
| ı Velorum | 5 | | 47 | 49 | 2·3 | 46 | 4·7 | 0·28 | |
| Argus | 4 | | 53 | 21 | 2·1 | 54 | 5·5 | 0·28 | |
| Antliæ | 6-5 | | 54 | 35 | 2·6 | 35 | 24·7 | 0·28 | |
| [ydræ, 193 G. | 6 | | 59 | 44 | 2·8 | 23 | 48·0 | 0·29 | |
| Velorum | 4 | 10 | 10 | 33 | 2·5 | 41 | 37·6 | 0·29 | |
| Argus | 4-3 | | 11 | 22 | 1·4 | 69 | 32·5 | 0·30 | |
| 'elorum, 202 G. | 6-7 | | 16 | 12 | 2·4 | 47 | 11·8 | 0·30 | |
| .ntliæ, 64 G. | 6-5 | | 19 | 7 | 2·6 | 37 | 30·1 | 0·30 | |
| Carinæ | 4-5 | | 22 | 25 | 1·2 | 73 | 31·3 | 0·30 | |
| Antliæ | 4-5 | | 22 | 34 | +2·7 | 30 | 33·5 | −0·30 | |

| No. | Name. | Mag. | R.A. 1900. | | | Ann. var. | Decl. 1900. | | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h | m | s | s | ° | ′ | ′ | |
| 195 | *s* Carinæ | 5–4 | 10 | 24 | 13 | +2·2 | −58 | 13·7 | −0·30 | |
| 196 | *p* Carinæ | 4–3 | | 28 | 28 | 2·1 | 61 | 10·2 | 0·31 | |
| 197 | 44 Hydræ | 6 | | 29 | 15 | 2·8 | 23 | 13·8 | 0·31 | |
| 198 | *p* Velorum | 4 | | 33 | 6 | 2·5 | 47 | 42·3 | 0·31 | |
| 199 | γ Chamæleontis | 4–5 | | 34 | 17 | 0·7 | 78 | 5·4 | 0·31 | |
| 200 | *x* Velorum | 5 | | 35 | 19 | 2·4 | 55 | 4·9 | 0·31 | |
| 201 | θ Argus | 3 | | 39 | 23 | 2·1 | 63 | 52·2 | 0·31 | |
| 202 | μ Argus | 3 | | 42 | 28 | 2·6 | 48 | 53·5 | 0·31 | |
| 203 | $\delta^2$ Chamæleontis | 5 | | 44 | 51 | 0·6 | 80 | 0·8 | 0·32 | 6 mag. pr.32ˢ b. |
| 204 | *u* Carinæ | 4 | | 49 | 25 | 2·4 | 58 | 19·3 | 0·32 | |
| 205 | ι Antliæ | 5 | | 52 | 3 | 2·8 | 36 | 35·9 | 0·32 | |
| 206 | *i* Velorum | 4–5 | | 55 | 33 | 2·7 | 41 | 41·3 | 0·32 | |
| 207 | χ Hydrae, 26 Hev. | 4–5 | 11 | 0 | 31 | 2·9 | 26 | 45·3 | 0·32 | |
| 208 | Carinæ, 259 G. | 6 | | 3 | 14 | 2·1 | 70 | 20·2 | 0·32 | |
| 209 | *x* Carinæ | 5–4 | | 4 | 19 | 2·5 | 58 | 26·0 | 0·32 | |
| 210 | 11 β Crateris | 4 | | 6 | 45 | 2·9 | 22 | 16·8 | 0·33 | |
| 211 | Carinæ, 264 G. | 6–5 | | 8 | 37 | 2·5 | 63 | 37·5 | 0·32 | |
| 212 | π Centauri | 4–5 | | 16 | 27 | 2·7 | 53 | 56·6 | 0.33 | |
| 213 | Centauri, 29 G. | 6–5 | | 20 | 39 | 2·9 | 35 | 30·8 | 0·33 | |
| 214 | ξ Hydrae | 4 | | 28 | 5 | 2·9 | 31 | 18·3 | 0·33 | |
| 215 | $C^2$ Centauri | 5–6 | | 31 | 5 | 2·9 | 47 | 5·2 | 0·33 | |
| 216 | λ Centauri | 3–4 | | 31 | 9 | 2·7 | 62 | 28·0 | 0·33 | |
| 217 | π Chamæleontis | 6 | | 33 | 8 | 2·5 | 75 | 20·6 | 0·33 | |
| 218 | *o* Hydræ | 5 | | 35 | 14 | 3·0 | 34 | 11·4 | 0·33 | |
| 219 | λ Muscæ | 4 | | 40 | 53 | 2·8 | 66 | 10·4 | 0·33 | |
| 220 | Centauri, 65 G. | 5–4 | | 41 | 41 | 2·9 | 60 | 37·3 | 0·33 | |
| 221 | Hydræ, 298 G. | 6 | | 43 | 42 | 3·0 | 26 | 11·6 | 0·33 | |
| 222 | *B* Centauri | 5 | | 46 | 9 | 3·0 | 44 | 37·0 | 0·33 | |
| 223 | Crucis, 2 G. | 6 | | 53 | 12 | 3·0 | 55 | 45·6 | 0·33 | |
| 224 | ε Chamæleontis | 5 | | 54 | 39 | 2·9 | 77 | 39·8 | 0·33 | |
| 225 | $\theta^1$ Crucis | 5–4 | | 57 | 56 | 3·0 | 62 | 45·3 | 0·33 | |
| 226 | Centauri, 88 G. | 6–5 | | 58 | 28 | 3·1 | 41 | 52·4 | 0·33 | |
| 227 | δ Centauri | 3 | 12 | 3 | 10 | 3·1 | 50 | 9·9 | 0·33 | |
| 228 | 2 ε Corvi | 3 | | 4 | 59 | 3·1 | 22 | 3·8 | 0·33 | |
| 229 | δ Crucis | 3–4 | | 9 | 50 | 3·1 | 58 | 11·5 | 0·33 | |
| 230 | ε Muscæ | 5–4 | | 12 | 11 | 3·2 | 67 | 24·2 | 0·33 | |
| 231 | β Chamæleontis | 5–4 | | 12 | 27 | 3·4 | 78 | 45·4 | 0·33 | |
| 232 | ε Crucis | 4 | | 15 | 58 | +3·2 | 59 | 50·9 | −0·33 | |

| | Name. | Mag. | R.A. 1900. | | | Ann. var. | Decl. 1900. | | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h | m | s | s | ° | ′ | ′ | |
| 3 | Centauri, 117 G. | 7–6 | 12 | 19 | 51 | +3·2 | −41 | 57·5 | −0·33 | |
| 4 | $x^2$ Centauri | 6 | | 20 | 6 | 3·1 | 34 | 37·9 | 0·33 | |
| 5 | Hydrae, 323 G. | 6–5 | | 21 | 36 | 3·1 | 32 | 16·5 | 0·33 | |
| 6 | σ Centauri | 4–5 | | 22 | 37 | 3·2 | 49 | 40·6 | 0·33 | |
| 7 | γ Crucis | 2 | | 25 | 37 | 3·3 | 56 | 33·1 | 0·34 | |
| 8 | γ Muscæ | 4 | | 26 | 30 | 3·5 | 71 | 34·8 | 0·33 | |
| 9 | 9 β Corvi | 2–3 | | 29 | 7 | 3·1 | 22 | 50·5 | 0·33 | |
| 0 | γ Centauri | 2–3 | | 36 | 0 | 3·3 | 48 | 24·6 | 0·33 | |
| 1 | Hydræ, 330 G. | 6 | | 38 | 41 | 3·2 | 27 | 46·5 | 0·33 | |
| 2 | β Muscæ | 3–4 | | 40 | 8 | 3·6 | 67 | 33·6 | 0·33 | |
| 3 | β Crucis | 2–1 | | 41 | 53 | 3·5 | 59 | 8·5 | 0·33 | |
| 4 | *p* Centauri | 5–6 | | 45 | 16 | 3·2 | 33 | 27·2 | 0·33 | |
| 5 | *n* Centauri | 4–5 | | 47 | 53 | 3·3 | 39 | 38·1 | 0·33 | |
| 6 | δ Muscæ | 4–3 | | 55 | 22 | 4·0 | 71 | 0·5 | 0·32 | |
| 7 | $\xi^2$ Centauri | 5 | 13 | 1 | 5 | 3·5 | 49 | 22·2 | 0·32 | |
| 8 | Centauri, 177 G. | 6 | | 1 | 42 | 3·5 | 52 | 55·4 | 0·32 | |
| 9 | Centauri, 183 G. | 5–6 | | 6 | 2 | 3·7 | 59 | 23·3 | 0·32 | |
| 0 | η Muscæ | 5–6 | | 8 | 28 | 4·0 | 67 | 21·8 | 0·32 | |
| 1 | *r* Centauri | 6–5 | | 11 | 20 | 3·3 | 30 | 58·5 | 0·32 | |
| 2 | Centauri, 196 G. | 6 | | 11 | 26 | 3·4 | 43 | 27·0 | 0.32 | |
| 3 | 46 γ Hydræ | 3–4 | | 13 | 29 | 3·2 | 22 | 38·5 | 0·32 | |
| 4 | ι Centauri | 3 | | 14 | 59 | 3·4 | 36 | 11·0 | 0·32 | |
| 5 | *d* Centauri | 4–5 | | 25 | 14 | 3·5 | 38 | 53·4 | 0·31 | |
| 6 | Hydræ, 350 G. | 6 | | 27 | 2 | 3·3 | 28 | 10·7 | 0·31 | |
| 7 | Chamæleontis, 49 G. | 6–7 | | 30 | 38 | 5·0 | 75 | 10·4 | 0·31 | |
| 8 | ε Centauri | 3–2 | | 33 | 33 | 3·8 | 52 | 57·5 | 0·31 | |
| 9 | 1 *i* Centauri | 4–5 | | 40 | 1 | 3·4 | 32 | 32·2 | 0·30 | |
| 0 | *M* Centauri | 5 | | 40 | 19 | 3·8 | 50 | 55·8 | 0·30 | |
| 1 | μ Centauri | 3–4 | | 43 | 36 | 3·6 | 41 | 58·5 | 0·30 | |
| 2 | ζ Centauri | 3–2 | | 49 | 18 | 3·7 | 46 | 47·7 | 0·30 | |
| 3 | Centauri, 294 G. | 6–5 | | 50 | 25 | 4·3 | 63 | 11·7 | 0.30 | |
| 4 | φ Centauri | 4 | | 52 | 11 | 3·6 | 41 | 36·7 | 0·29 | |
| 5 | 47 Hydræ | 6 | | 52 | 55 | 3·4 | 24 | 29·1 | 0·29 | |
| 6 | 49 π Hydræ | 4–3 | 14 | 0 | 40 | 3·4 | 26 | 11·9 | 0·29 | |
| 7 | 5 θ Centauri | 3–2 | | 0 | 48 | 3·5 | 35 | 52·6 | 0·30 | 11 mag. 3′ |
| 8 | η Apodis | 5–6 | | 5 | 38 | 7·1 | 80 | 32·3 | 0·29 | |
| 9 | ι Lupi | 4 | | 13 | 0 | 3·8 | 45 | 35·8 | 0·28 | |
| 0 | υ Centauri | 5 | | 13 | 20 | +4·1 | 55 | 55·5 | −0·28 | |

| No. | Name. | Mag. | R.A. 1900. | | | Ann. var. | Decl. 1900. | | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h | m | s | s | ° | ′ | ′ | |
| 271 | Circini, 10 G. | 6 | 14 | 16 | 48 | +4·9 | 67 | 44·4 | −0·28 | |
| 272 | *a* Centauri | 5 | | 16 | 53 | 3·7 | 39 | 3·2 | 0·28 | |
| 273 | Libræ, 3 G. | 6–5 | | 19 | 6 | 3·4 | 24 | 21·1 | 0·27 | |
| 274 | 52 Hydræ | 5-6 | | 22 | 18 | 3·5 | 29 | 2·5 | 0·27 | |
| 275 | η Centauri | 2-3 | | 29 | 10 | 3·8 | 41 | 43·1 | 0·27 | |
| 276 | α Lupi | 3·2 | | 35 | 17 | 4·0 | 46 | 57·5 | 0·26 | |
| 277 | α Apodis | 4 | | 35 | 25 | 7·1 | 78 | 37·1 | 0·26 | |
| 278 | Circini, 19 G. | 6 | | 37 | 21 | 4·7 | 62 | 26·9 | 0·26 | 7 mag. pr. 1m46s a. |
| 279 | $c^1$ Centauri | 4–5 | | 37 | 32 | 3·6 | 34 | 44·5 | 0·26 | |
| 280 | *b* Lupi | 6 | | 40 | 2 | 4·2 | 51 | 57·6 | 0·26 | 6 mag. seq. 11s b. 1 |
| 281 | Apodis 18 G. | 6 | | 46 | 28 | 6·6 | 76 | 15·3 | 0·25 | |
| 282 | Circini, 29 G. | 6 | | 47 | 53 | 4·6 | 59 | 42·1 | 0·25 | |
| 283 | Centauri, 381 G. | 6 | | 49 | 36 | 3·7 | 33 | 27·0 | 0·25 | |
| 284 | β Lupi | 3 | | 51 | 58 | 3·9 | 42 | 43·9 | 0·25 | |
| 285 | γ Scorpii 1 Hev. | 3-4 | | 58 | 12 | 3·5 | 24 | 53·3 | 0·24 | |
| 286 | π Lupi | 4–5 | | 58 | 18 | 4·1 | 46 | 39·6 | 0·24 | |
| 287 | ζ Lupi | 4–3 | 15 | 5 | 7 | 4·3 | 51 | 43·1 | 0·23 | |
| 288 | γ Trianguli austr. | 3 | | 9 | 33 | 5·5 | 68 | 18·6 | 0·23 | |
| 289 | β Circini | 5–4 | | 9 | 41 | 4·7 | 58 | 25·6 | 0·23 | |
| 290 | δ Lupi | 4–3 | | 14 | 48 | 3·9 | 40 | 17·1 | 0·22 | |
| 291 | $\phi^1$ Lupi | 4-3 | | 15 | 28 | 3·8 | 35 | 53·9 | 0·22 | |
| 292 | $\kappa^1$ Apodis | 6 | | 20 | 36 | 6·4 | 73 | 2·5 | 0·22 | |
| 293 | ε Trianguli austr. | 5–4 | | 27 | 33 | 5·4 | 65 | 58·8 | 0·21 | |
| 294 | γ Lupi | 3 | | 28 | 8 | 4·0 | 40 | 49·9 | 0·21 | |
| 295 | Scorpii 3 Hev. | 4–5 | | 30 | 57 | 3·6 | 27 | 48·3 | 0·20 | |
| 296 | Normæ, 2 G. | 6 | | 31 | 24 | 4·4 | 52 | 2·6 | 0·20 | |
| 297 | 5 χ Lupi | 5–4 | | 44 | 36 | 3·8 | 33 | 19·3 | 0·19 | |
| 298 | β Trianguli austr. | 3 | | 46 | 20 | 5·2 | 63 | 7·3 | 0·19 | |
| 299 | 5 ρ Scorpii | 5–4 | | 50 | 42 | 3·7 | 28 | 55·3 | 0·18 | |
| 300 | 7 δ Scorpii | 2–3 | | 54 | 25 | 3·5 | 22 | 20·2 | 0·17 | |
| 301 | δ Normæ | 5 | | 59 | 25 | 4·2 | 44 | 54·1 | 0·17 | |
| 302 | θ Lupi | 5 | 16 | 0 | 1 | 3·9 | 36 | 31·8 | 0·17 | |
| 303 | 10 $\omega^2$ Scorpii | 5 | | 1 | 33 | 3·5 | 20 | 36·0 | 0·17 | 9 $\omega^1$ 4–5 mag. pr. b. 12′·0 |
| 304 | κ Normae | 5–6 | | 5 | 35 | 4·7 | 54 | 22·2 | 0·16 | |
| 305 | δ Trianguli austr. | 4–5 | | 6 | 20 | 5·4 | 63 | 25·8 | 0·16 | |
| 306 | $\gamma^2$ Normæ | 5-4 | | 12 | 21 | 4·5 | 49 | 54·6 | 0·15 | |
| 307 | 20 σ Scorpii | 3–4 | | 15 | 7 | 3·6 | 25 | 21·1 | 0·15 | 9 mag. 21″ |
| 308 | Scorpii, 62 G. | 6 | | 17 | 15 | +4·0 | 38 | 57·6 | −0·15 | |

| No. | Name. | Mag. | R.A. 1900. h | m | s | Ann. var. s | Decl. 1900. ° | ′ | Ann. var. ′ | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 309 | ζ Trianguli austr. | 6–5 | 16 | 17 | 41 | +6·3 | −69 | 51·6 | −0·15 | |
| 310 | γ Apodis | 4 | | 18 | 6 | 9·0 | 78 | 40·3 | 0·15 | |
| 311 | Trianguli austr., 33 G. | 6 | | 21 | 56 | 5·3 | 61 | 24·7 | 0·14 | |
| 312 | Normæ, 59 G. | 6 | | 22 | 27 | 4·3 | 46 | 1·3 | 0·14 | |
| 313 | *N* Scorpii | 5–4 | | 24 | 51 | 3·9 | 34 | 29·2 | 0·14 | |
| 314 | μ Normæ | 5–6 | | 26 | 58 | 4·2 | 43 | 50·0 | 0·13 | |
| 315 | β Apodis | 4–5 | | 28 | 47 | 8·4 | 77 | 18·4 | 0·14 | |
| 316 | 23 τ Scorpii | 3–4 | | 29 | 39 | 3·7 | 28 | 0·3 | 0·12 | |
| 317 | α Trianguli austr. | 2 | | 38 | 4 | 6·3 | 68 | 50·6 | 0·12 | |
| 318 | η Aræ | 4 | | 41 | 9 | 5·1 | 58 | 51·8 | 0·11 | |
| 319 | 26 ε Scorpii | 3 | | 43 | 42 | 3·9 | 34 | 6·7 | 0·11 | |
| 320 | $\mu^1$ Scorpii | 4–3 | | 45 | 5 | 4·0 | 37 | 52·5 | 0·11 | |
| 321 | $\zeta^2$ Scorpii | 4–3 | | 47 | 33 | 4·2 | 42 | 11·4 | 0·11 | |
| 322 | ζ Aræ | 3 | | 50 | 20 | 4·9 | 55 | 50·0 | 0·10 | |
| 323 | 24 Ophiuchi | 6 | | 50 | 46 | 3·6 | 22 | 59·5 | 0·10 | |
| 324 | $\epsilon^1$ Aræ | 4 | | 51 | 37 | 4·8 | 53 | 0·4 | 0·10 | |
| 325 | Scorpii, 117 G. | 6–5 | | 55 | 25 | 3·9 | 31 | 59·7 | 0·09 | |
| 326 | η Scorpii | 4–3 | 17 | 4 | 59 | 4·3 | 43 | 6·5 | 0·09 | |
| 327 | Scorpii, 139 G. | 6 | | 10 | 33 | 3·9 | 32 | 32·9 | 0·07 | |
| 328 | ι Apodis | 6 | | 10 | 56 | 6·6 | 70 | 1·0 | 0·07 | 7 mag. pr. $1^m 49^s$ b. 5′·4 |
| 329 | 40 ξ Ophiuchi | 5 | | 14 | 59 | 3·6 | 21 | 0·3 | 0·07 | |
| 330 | 42 θ Ophiuchi | 3–4 | | 15 | 52 | 3·7 | 24 | 53·9 | 0·06 | |
| 331 | β Aræ | 3 | | 16 | 59 | 5·0 | 55 | 26·1 | 0·06 | |
| 332 | 44 Ophiuchi | 4–5 | | 20 | 15 | 3·7 | 24 | 5·0 | 0·06 | |
| 333 | 45 *d* Ophiuchi | 5 | | 20 | 57 | 3·8 | 29 | 46·5 | 0·06 | |
| 334 | δ Aræ | 4–3 | | 22 | 4 | 5·4 | 60 | 36·0 | 0·06 | |
| 335 | α Aræ | 3 | | 24 | 7 | 4·6 | 49 | 47·8 | 0·05 | |
| 336 | 51 Ophiuchi | 5 | | 25 | 18 | 3·7 | 23 | 53·1 | 0·05 | |
| 337 | 35 λ Scorpii | 2–3 | | 26 | 49 | 4·1 | 37 | 1·8 | 0·05 | |
| 338 | π Aræ | 6 | | 29 | 53 | 4·9 | 54 | 26·0 | 0·05 | |
| 339 | θ Scorpii | 2 | | 30 | 7 | 4·3 | 42 | 56·0 | 0·04 | |
| 340 | κ Scorpii | 3–2 | | 35 | 34 | 4·1 | 38 | 58·7 | 0·04 | |
| 341 | η Pavonis | 4–3 | | 35 | 55 | 5·9 | 64 | 40·5 | 0·04 | |
| 342 | μ Aræ | 6–5 | | 36 | 12 | 4·8 | 51 | 46·7 | 0·04 | |
| 343 | $\iota^1$ Scorpii | 3–4 | | 40 | 36 | 4·2 | 40 | 5·2 | 0·03 | |
| 344 | 3 *X* Sagittarii | 4–6 | | 41 | 15 | 3·8 | 27 | 47·5 | 0·03 | |
| 345 | *G* Scorpii | 3–4 | | 43 | 3 | 4·1 | 37 | 0·7 | 0·03 | |
| 346 | Apodis, 66 G. | 6 | | 57 | 17 | +8·4 | 75 | 53·5 | −0·01 | |

| No. | Name. | Mag. | R.A. 1900. h m s | Ann. var. s | Decl. 1900. ° ′ | Ann. var. ′ | Remarks. |
|---|---|---|---|---|---|---|---|
| 347 | π Pavonis | 5-4 | 17 58 57 | +5·8 | −63 40·3 | −0·01 | |
| 348 | 10 γ Sagittarii | 3 | 59 23 | 3·8 | 30 25·6 | 0·00 | |
| 349 | ε Telescopii | 5 | 18 3 48 | 4·4 | 45 58·3 | 0·00 | |
| 350 | 13 μ Sagittarii | 4 | 7 46 | 3·6 | 21 5·1 | +0·01 | |
| 351 | Telescopii, 6 G. | 6-5 | 8 42 | 5·1 | 56 3·3 | 0·01 | |
| 352 | η Sagittarii | 3-4 | 10 51 | 4·1 | 36 47·5 | 0·01 | |
| 353 | ξ Pavonis | 4-5 | 14 0 | 5·5 | 61 32·4 | 0·02 | |
| 354 | 19 δ Sagittarii | 3 | 14 35 | 3·8 | 29 52·3 | 0·02 | |
| 355 | 20 ε Sagittarii | 2-3 | 17 32 | 4·0 | 34 25·9 | 0·02 | |
| 356 | α Telescopii | 3-4 | 19 33 | 4·4 | 46 1·5 | 0·02 | |
| 357 | Pavonis, 30 G. | 6-7 | 20 5 | 7·7 | 74 1·7 | 0·02 | |
| 358 | 22 λ Sagittarii | 3 | 21 47 | 3·7 | 25 28·7 | 0·02 | |
| 359 | θ Coronæ austr. | 5 | 26 22 | 4·3 | 42 23·1 | 0·04 | |
| 360 | ζ Pavonis | 4 | 31 21 | 7·0 | 71 30·8 | 0·04 | |
| 361 | Br. 2333 | 6 | 32 25 | 3·6 | 23 35·4 | 0·04 | |
| 362 | λ Coronæ austr. | 5-6 | 36 55 | 4·1 | 38 25·1 | 0·05 | |
| 363 | Pavonis, 41 G. | 6 | 37 25 | 7·4 | 73 6·2 | 0·05 | |
| 364 | $\eta^1$ Coronæ austr. | 6-5 | 41 37 | 4·3 | 43 47·4 | 0·06 | |
| 365 | λ Pavonis | 4-5 | 42 57 | 5·6 | 62 18·1 | 0·06 | |
| 366 | 30 Sagittarii | 6-7 | 44 50 | 3·6 | 22 16·6 | 0·06 | |
| 367 | κ Pavonis | 5 | 46 38 | 6·2 | 67 21·6 | 0·06 | |
| 368 | 34 σ Sagittarii | 2-3 | 49 4 | 3·7 | 26 25·2 | 0·07 | |
| 369 | λ Telescopii | 5 | 50 27 | 4·8 | 53 4·2 | 0·07 | |
| 370 | ε Coronæ austr. | 5-6 | 51 58 | 4·1 | 37 14·3 | 0·07 | |
| 371 | 38 ζ Sagittarii | 3 | 56 14 | 3·8 | 30 1·4 | 0·08 | dpl. 4 mag. & 4 m 0″·4 |
| 372 | ρ Telescopii | 6-5 | 58 25 | 4·8 | 52 29·3 | 0·08 | |
| 373 | 40 τ Sagittarii | 4-3 | 19 0 42 | 3·7 | 27 49·0 | 0·08 | |
| 374 | α Coronæ austr. | 4 | 2 40 | 4·1 | 38 3·7 | 0·08 | |
| 375 | 41 π Sagittarii | 3 | 3 49 | 3·6 | 21 11·0 | 0·09 | |
| 376 | Pavonis, 60 G. | 6-5 | 7 9 | 6·1 | 66 50·0 | 0·09 | |
| 377 | Coronæ austr., 49 G. | 6-7 | 7 23 | 4·4 | 45 21·7 | 0·09 | |
| 378 | α Sagittarii | 4 | 16 57 | 4·2 | 40 48·2 | 0·11 | |
| 379 | Telescopii, 59 G. | 6 | 19 46 | 4·8 | 54 31·5 | 0·11 | |
| 380 | Sagittarii, 186 G. | 6 | 20 37 | 3·8 | 29 56·5 | 0·11 | |
| 381 | ι Telescopii | 5-6 | 27 48 | 4·5 | 48 18·8 | 0·12 | |
| 382 | 52 h Sagittarii | 5-4 | 31 13 | 5·1 | 25 6·2 | 0·13 | 11 mag. 3″ |
| 383 | Pavonis, 70 G. | 6-5 | 37 53 | 7·0 | 72 44·8 | 0·13 | |
| 384 | Sagittarii, 228 G. | 6-5 | 39 39 | +3·8 | 32 9·1 | +0·14 | |

| Name. | Mag. | R.A. 1900. | Ann. var. | Decl. 1900. | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|
| | | h m s | s | ° ′ | ″ | |
| ν Telescopii | 5–6 | 19 39 51 | +4·9 | −56 36·2 | +0·14 | |
| 56 *f* Sagittarii | 5 | 40 32 | 3·5 | 20 0·0 | 0·14 | |
| Pavonis, 75 G. | 6 | 45 57 | 5·3 | 61 25·7 | 0·15 | |
| ι Sagittarii | 4–5 | 48 22 | 4·1 | 42 7·8 | 0·15 | |
| ε Pavonis | 4 | 49 2 | 7·0 | 73 10·5 | 0·15 | |
| $\theta^1$ Sagittarii | 4–5 | 53 14 | 3·9 | 35 32·8 | 0·16 | |
| 62 *c* Sagittarii | 5 | 56 30 | 3·7 | 27 59·3 | 0·16 | |
| Sagittarii, 269 G. | 6–7 | 57 49 | 3·6 | 22 52·0 | 0·16 | |
| δ Pavonis | 3–4 | 58 56 | 5·9 | 66 26·2 | 0·15 | |
| ξ Telescopii | 5–6 | 59 44 | 4·6 | 53 10·0 | 0·16 | |
| 4 Capricorni | 6 | 20 12 9 | 3·5 | 22 7·1 | 0·18 | |
| $\kappa^1$ Sagittarii | 5–6 | 15 40 | 4·1 | 42 21·8 | 0·18 | |
| α Pavonis | 2 | 17 45 | 4·8 | 57 3·4 | 0·18 | |
| Sagittarii, 296 G. | 6 | 19 19 | 3·7 | 28 59·3 | 0·19 | |
| ρ Pavonis | 5 | 29 12 | 5·1 | 61 52·4 | 0·20 | |
| $\mu^1$ Octantis | 6–7 | 29 41 | 7·6 | 76 31·8 | 0·20 | |
| α Indi | 3 | 30 32 | 4·2 | 47 38·4 | 0·20 | |
| Microscopii, 13 G. | 6 | 34 3 | 3·8 | 33 47·1 | 0·21 | |
| β Pavonis | 3–4 | 35 57 | 5·5 | 66 33·8 | 0·21 | |
| η Indi | 5–4 | 36 41 | 4·4 | 52 16·7 | 0·21 | |
| 16 ψ Capricorni | 4–5 | 40 10 | 3·6 | 25 37·8 | 0·21 | |
| ι Microscopii | 5–6 | 41 42 | 4·1 | 44 21·1 | 0·21 | |
| 18 ω Capricorni | 4–5 | 45 52 | 3·6 | 27 17·6 | 0·22 | |
| β Indi | 4–3 | 46 59 | 4·7 | 58 49·9 | 0·22 | |
| Microscopii, 33 G. | 6–5 | 47 10 | 3·9 | 40 11·0 | 0·22 | |
| α Octantis | 6–5 | 52 38 | 7·5 | 77 24·3 | 0·22 | |
| γ Microscopii | 5 | 55 9 | 3·7 | 32 39·0 | 0·23 | |
| ζ Microscopii | 5–6 | 56 34 | 3·9 | 39 1·2 | 0·23 | |
| 24 *A* Capricorni | 5 | 21 1 17 | 3·5 | 25 24·3 | 0·24 | |
| ο Pavonis | 5–6 | 3 58 | 5·7 | 70 32·1 | 0·24 | |
| Indi, 23 G. | 6 | 8 38 | 4·3 | 53 40·1 | 0·24 | |
| 4 Piscis austr. | 5 | 11 52 | 3·6 | 32 35·4 | 0·25 | |
| $\theta^1$ Microscopii | 5 | 14 22 | 3·8 | 41 14·0 | 0·25 | |
| γ Pavonis | 4–5 | 18 11 | 5·0 | 65 49·1 | 0·27 | |
| γ Indi | 6–7 | 19 8 | 4·3 | 55 5·6 | 0·25 | |
| 34 ζ Capricorni | 4 | 20 58 | 3·4 | 22 50·7 | 0·26 | |
| Gruis, 3 G. | 6 | 26 55 | 3·9 | 45 17·5 | 0·26 | |
| Indi, 40 G. | 6–7 | 30 4 | +4·9 | 65 16·3 | +0·26 | |

| No. | Name. | Mag. | R.A. 1900. h | m | s | Ann. var. s | Decl. 1900. ° | ′ | Ann. var. ′ | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 423 | ν Octantis | 4 | 21 | 30 | 22 | +6·9 | −77 | 48·9 | +0·26 | |
| 424 | 41 Capricorni | 6–5 | | 36 | 18 | 3·4 | 23 | 42·9 | 0·27 | |
| 425 | 9 ι Piscis austr. | 5 | | 39 | 0 | 3·6 | 33 | 29·0 | 0·27 | |
| 426 | ο Indi | 6–5 | | 42 | 21 | 5·2 | 70 | 5·6 | 0·27 | |
| 427 | γ Gruis | 3 | | 47 | 52 | 3·6 | 37 | 50·2 | 0·28 | |
| 428 | δ Indi | 5 | | 51 | 7 | 4·1 | 55 | 28·1 | 0·28 | |
| 429 | Capricorni, 134 G. | 7–6 | | 53 | 9 | 3·3 | 21 | 39·6 | 0·28 | |
| 430 | ε Indi | 5 | | 55 | 43 | 4·6 | 57 | 11·8 | 0·25 | |
| 431 | λ Gruis | 5–4 | 22 | 0 | 6 | 3·6 | 40 | 1·5 | 0·29 | |
| 432 | α Gruis | 2 | | 1 | 56 | 3·8 | 47 | 26·7 | 0·29 | |
| 433 | 14 μ Piscis austr. | 5–4 | | 2 | 33 | 3·5 | 33 | 28·6 | 0·29 | |
| 434 | 16 λ Piscis austr. | 5 | | 8 | 38 | 3·4 | 28 | 15·7 | 0·29 | |
| 435 | ε Octantis | 6–5 | | 8 | 50 | 7·1 | 80 | 56·3 | 0·29 | |
| 436 | $\mu^1$ Gruis | 5 | | 9 | 36 | 3·6 | 41 | 50·7 | 0·29 | |
| 437 | α Tucanæ | 3 | | 11 | 38 | 4·2 | 60 | 45·5 | 0·29 | |
| 438 | Gruis, 37 G. | 6–5 | | 11 | 41 | 3·9 | 54 | 6·3 | 0·30 | |
| 439 | ν Indi | 6–5 | | 15 | 55 | 5·0 | 72 | 44·2 | 0·30 | |
| 440 | 47 Aquarii | 6–5 | | 16 | 6 | 3·3 | 22 | 5·8 | 0·30 | |
| 441 | ν Gruis | 6–5 | | 22 | 47 | 3·5 | 39 | 38·2 | 0·30 | 7 mag. pr. 25ˢ b. 2 |
| 442 | $\delta^1$ Gruis | 4 | | 23 | 18 | 3·6 | 44 | 0·4 | 0·30 | $\delta^2$ 4–5 mag. seq. a. 15′·3 |
| 443 | ν Tucanæ | 5–6 | | 26 | 15 | 4·1 | 62 | 29·8 | 0·30 | |
| 444 | 59 υ Aquarii | 5–6 | | 29 | 13 | 3·3 | 21 | 13·1 | 0·31 | |
| 445 | Piscis austr., 49 G. | 6 | | 33 | 13 | 3·4 | 33 | 36·2 | 0·31 | |
| 446 | 18 ε Piscis austr. | 4 | | 35 | 7 | 3·3 | 27 | 34·0 | 0·31 | |
| 447 | β Octantis | 4–5 | | 35 | 53 | 6·6 | 81 | 54·4 | 0·31 | |
| 448 | β Gruis | 2 | | 36 | 42 | 3·6 | 47 | 24·5 | 0·31 | |
| 449 | ε Gruis | 3–4 | | 42 | 31 | 3·6 | 51 | 50·6 | 0·31 | |
| 450 | Gruis, 69 G. | 6 | | 45 | 21 | 3·4 | 39 | 41·2 | 0·32 | |
| 451 | Tucanæ, 18 G. | 6 | | 45 | 41 | 3·9 | 63 | 43·1 | 0·32 | |
| 452 | 22 γ Piscis austr. | 5–4 | | 46 | 58 | 3·3 | 33 | 24·4 | 0·32 | 9 mag. 4″ |
| 453 | ρ Indi | 6 | | 47 | 43 | 4·3 | 70 | 36·5 | 0·32 | |
| 454 | ζ Gruis | 4 | | 54 | 58 | 3·6 | 53 | 17·4 | 0·32 | |
| 455 | Indi, 80 G. | 6 | | 58 | 16 | 4·0 | 69 | 21·7 | 0·32 | |
| 456 | θ Gruis | 4 | 23 | 1 | 15 | 3·4 | 44 | 3·7 | 0·32 | |
| 457 | 86 $c^1$ Aquarii | 4–5 | | 1 | 19 | 3·2 | 24 | 17·0 | 0·32 | |
| 458 | 88 $c^2$ Aquarii | 4 | | 4 | 7 | 3·2 | 21 | 42·9 | 0·32 | |
| 459 | ι Gruis | 4 | | 4 | 42 | 3·4 | 45 | 47·3 | 0·32 | Com. 10 mag. |
| 460 | Tucanæ, 25 G. | 6–5 | | 10 | 57 | +3·6 | 62 | 32·7 | +0·33 | |

| No. | Name. | Mag. | R.A. 1900. | | | Ann. var. | Decl. 1900. | | Ann. var. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | h | m | s | s | ° | ′ | ′ | |
| 461 | γ Tucanæ | 4 | 23 | 11 | 36 | +3·5 | −58 | 47·0 | +0·33 | |
| 462 | γ Sculptoris | 4–5 | | 13 | 25 | 3·2 | 33 | 4·7 | 0·32 | |
| 463 | Sculptoris, 11 G. | 6 | | 15 | 56 | 3·2 | 27 | 32·0 | 0·33 | |
| 464 | 98 $b^1$ Aquarii | 4–5 | | 17 | 44 | 3·1 | 20 | 38·7 | 0·33 | |
| 465 | *o* Gruis | 6–5 | | 21 | 1 | 3·4 | 53 | 16·6 | 0·33 | |
| 466 | Tucanæ, 33 G. | 6 | | 23 | 14 | 3·5 | 63 | 39·7 | 0·33 | |
| 467 | Octantis, 83 G. | 6 | | 26 | 52 | 4·0 | 77 | 56·3 | 0·33 | |
| 468 | β Sculptoris | 5 | | 27 | 37 | 3·2 | 38 | 22·2 | 0·33 | |
| 469 | 101 $b^3$ Aquarii | 5–4 | | 28 | 3 | 3·1 | 21 | 28·0 | 0·33 | |
| 470 | ι Phœnicis | 4–5 | | 29 | 42 | 3·2 | 43 | 10·0 | 0·33 | |
| 471 | Phœnicis, 11 G. | 4–5 | | 32 | 28 | 3·2 | 46 | 2·7 | 0·33 | |
| 472 | μ Sculptoris | 5–6 | | 35 | 23 | 3·2 | 32 | 37·6 | 0·33 | |
| 473 | Tucanæ, 35 G. | 6–7 | | 38 | 41 | 3·5 | 71 | 2·9 | 0·33 | |
| 474 | σ Phœnicis | 5 | | 41 | 57 | 3·2 | 50 | 46·9 | 0·33 | |
| 475 | δ Sculptoris | 5–4 | | 43 | 43 | 3·1 | 28 | 41·0 | 0·33 | |
| 476 | Aquarii, 274 G. | 6–7 | | 48 | 11 | 3·1 | 24 | 47·1 | 0·33 | |
| 477 | π Phœnicis | 5 | | 53 | 44 | 3·1 | 53 | 18·3 | 0·33 | |
| 478 | ε Tucanæ | 4–5 | | 54 | 43 | 3·2 | 66 | 8·0 | 0·33 | |
| 479 | θ Octantis | 5–6 | | 56 | 29 | 3·2 | 77 | 37·0 | 0·33 | |
| 480 | Tucanæ, 45 G. | 6 | | 59 | 37 | +3·1 | −71 | 59·6 | +0·33 | |

## *Measures of Southern Double Stars, made at the Observatory, Sydney, New South Wales.*

(*Communicated by H. C. Russell, B.A., F.R.S.*)

The following are measures of interesting southern double stars made at Sydney Observatory during 1886 with two measures of *α Centauri* in 1884. With a view of testing the measures of position-angles several measures of *α Centauri* have been made. Taking $\Delta\alpha$ and $\Delta\delta$, it will be seen that the results obtained in this way by Mr. Pollock are rather less than his direct measures, but he thinks his direct measures are more reliable. There is some discrepancy in the measures of *h* 5028, the large star of which Burnham discovered to be double (B 759), and β makes the distance of the wide pair 34″·81. Herschel gives two measures with his reflector distances, 20″ and 15″, and the Sydney measure in 1886 is 15″·27.

*Results of Measures of a Centauri, Sydney Observatory,* 1884 *and* 1886.

| Star. | R.A. 1886·0. | Decl. 1886·0. | Pos. Angle. | Dist. | Mags. | Date. | Observer. | Instrument. | |
|---|---|---|---|---|---|---|---|---|---|
| | h m s | | ° | ″ | | | | | |
| α Centauri | 14 31 52 | −60 21 46 | 199·0 | 11·96 | 1–1½ | 1884·194 | R. | 11½ | |
| | | | 202·7 | 14·78 | | 86·296 | P. | 7¼ | |
| | | | 202·9 | 15·02 | | 86·301 | P. | 7¼ | Definition bad. |
| | | | 202·7 | 15·09 | | 86·320 | P. | 7¼ | Stars very blazy. |
| | | | 202·3 | 14·73 | | 86·326 | P. | 7¼ | Stars very blazy. |
| | | | 200·4 | 14·74 | | 86·378 | R. | 11½ | |
| | | | 201·9 | 14·84 | | 86·378 | P. | 11½ | |
| | | | 201·2 | 15·19 | | 86·520 | R. | 11½ | |
| | | | 201·9 | 15·37 | | 86·526 | P. | 7¼ | Definition very unsteady. |
| | | | 202·3 | 14·70 | | 86·534 | P. | 7¼ | Definition awful. |
| | | | 202·6 | 15·06 | | 86·548 | P. | 7¼ | 4 o'clock P.M. |
| | | | 202·2 | 15·15 | | 86·550 | P. | 7¼ | 2.30 P.M., stars dancing. |
| | | | 202·7 | -- | | 86·550 | P. | 7¼ | 4.30 P.M., stars very steady. |
| | | | 202·7 | 14·96 | | 86·553 | P. | 7¼ | Pos. angle satisfactory. |
| | | | 203·1 | 15·25 | | 86·567 | P. | 7¼ | |
| | | | 202·2 | 15·21 | | 86·570 | P. | 7¼ | |
| | | | 202·6 | 15·00 | | 86·583 | P. | 7¼ | Definition very steady. |
| | | | 202·5 | 14·96 | | 86·594 | P. | 7¼ | |
| | | | 202·1 | 15·63 | | 86·602 | P. | 7¼ | Definition good. |

| | Observer. | Epoch. | Pos. Angle. | Dist. | No. of Meas. |
|---|---|---|---|---|---|
| | | | ° | ″ | |
| Mean ... ... ... | R. | 1886·449 | 200·80 | 14·97 | 2 |
| | P. | 1886·487 | 202·46 | 15·05 | 16 |

*Resulting Position-angles and Distances of α Centauri obtained from Measures Δα and Δδ, Sydney Observatory, 1884 and 1886.*

| | Pos. Angle. | Distance. | Date. | Observer. | Instrument. |
|---|---|---|---|---|---|
| | ° | " | | | |
| | 199·5 | 12·32 | 1884·433 | R. | $11\frac{1}{3}$ |
| | 200·7 | 14·68 | 86·526 | P. | $7\frac{1}{4}$ |
| | 200·9 | 14·82 | 86·548 | P. | $7\frac{1}{4}$ |
| | 201·8 | 14·78 | 86·550 | P. | $7\frac{1}{4}$ |
| | 200·7 | 15·19 | 86·567 | P. | $7\frac{1}{4}$ |
| | **Observer.** | **Epoch.** | **Pos. Angle.** | **Dist.** | **No. of Meas.** |
| | | | ° | " | |
| Mean... .. ... | P. | 1886·548 | 201·02 | 14·87 | 4 |

*Measures of some Southern Binaries and Double Stars showing signs of Motion, made at Sydney Observatory during the year 1886.*

| Star. | R.A. 1886·0. | Dec. 1886·0. | Pos. Angle. | Dist. | Mags. | Date. | Obs. | Instr. | |
|---|---|---|---|---|---|---|---|---|---|
| | h m s | ° ′ ″ | ° | " | | | | | |
| *p* Eridani | 1 35 28 | −56 46 27 | 229·9 | 6·63 | 6–6 | 1886·901 | P. | $11\frac{1}{3}$ | Definition very bad. |
| | | | 230·8 | 6·85 | „ | 86·909 | P. | $11\frac{1}{3}$ | Definition good. |
| β Muscæ | 12 39 18 | −67 29 2 | 322·0 | 0·79 | 3·5–4 | 86·501 | R. | $11\frac{1}{3}$ | Discovered double by Russell 78·284. |
| | | | 325·8 | 0·5 est. | „ | 86·594 | P. | $7\frac{1}{4}$ | |
| | | | 323·7 | — | „ | 86·597 | P. | $7\frac{1}{4}$ | Previous measure— R 80·344 Pos. 317°·3 Dist. 0″·54 |
| MM π Lupi | 14 57 22 | −46 36 15 | 91·1 | 0·87 | 5–5 | 86·550 | P. | $7\frac{1}{4}$ | Previous measures— *h* 1836·11 Pos. 111°·1 Dist. 0″·75 |
| | | | 89·8 | 0·8 est. | — | 86·597 | P. | $7\frac{1}{4}$ | R 1872·422 „ 100°·1 „ 0″·57 |
| | | | | | | | | | R 1880·444 „ 99°·3 „ 0″·90 |

| Star. | R.A. 1886·0. | Dec. 1886·0. | Pos. Angle. | Dist. | Mags. | Date. | Obs. | Instr. | |
|---|---|---|---|---|---|---|---|---|---|
| | h m s | ° ′ ″ | ° | ″ | | | | | |
| *h* 5027 | 18 3 0 | −54 25 0 | 95·2 | 12·90 | 9–10 | 86·597 | P. | 7¼ | Previous measures— *h* 1834·518 Pos. 59°·2 Dist. 15″ est. R 71·548 „ 84°·7 Dist. 12″·98 H (Sydney) 81·706 Pos. 91°·9 Dist. 11″·42 |
| *h* 5078 | 18 54 0 | 45 49 0 | 212·3 | 18·88 | 9–10 | 86·597 | P. | 7¼ | A and B } Large star discovered double by Russell 81·716. Previous measure— |
| | | | 275·3 | 1·80 | 9–10 | 86·597 | P. | 7¼ | A and C } R 81·716 Pos. 287°·3 Dist. 1″·00 |
| ζ Sagittarii | 18 55 21 | −30 2 30 | 271·0 | — | 3·5-4 | 86·739 | P. | 11½ | Elongated with 800 and 1200, but not divided; smaller end goes first. The star appears pear-shaped. Measures made with 800 power, 9-in. aperture; definition first rate. Looked at on (5) nights, but above was only night it could be measured. Est. dist. less than ½″. For previous measures see a paper by Mr. Goro, *Monthly Notices*, vol. xlvi. 8. |
| γ Coronæ austr. | 18 58 43 | −37 13 33 | 199·6 | 1·70 | 5 5 | 86·567 | P. | 7¼ | Measures difficult; dist. not satisfactory. |
| | | | 200·5 | 1·40 | | 86·570 | P. | 7¼ | |
| | | | 199·9 | 1·11 | | 86·572 | P. | 7¼ | Cloudy; dist. not reliable. |
| | | | 200·5 | 1·35 | | 86·591 | P. | 7¼ | |
| | | | 200·9 | 1·06 | | 86·597 | P. | 7¼ | Distance not satisfactory. |
| | | | 200·6 | 1·64 | | 86·613 | P. | 7¼ | |
| | | | 203·5 | 1·52 | | 86·704 | R. | 11½ | |
| | | | 201·3 | 1·74 | | 86·704 | P. | 11½ | |
| | | | 201·4 | 1·63 | | 86·706 | P. | 11½ | |
| Mean ... | ... ... | ... ... | 200·59 | 1·45 | | 1886·615 | P | | 8 measures. |
| γ Lupi | 15 27 0 | 40 47 0 | Looked at on several nights; not divided with highest powers; seems elongated in direction of motion. | | | | | | |

| Star. | R.A. 1886·0. h m s | Decl. 1886·0. ° ′ | Pos. Angle. ° | Dist. ″ | Mags. | Date. | Obs. | Instr. | |
|---|---|---|---|---|---|---|---|---|---|
| β 755 | 6 31 26 | −36 41 | 252·3 | 0·88 | 6–7 | 1887·227 | P. | $11\frac{1}{3}$ | A and B. |
| | | | 253·0 | 0·67 | | 87·246 | P. | $11\frac{1}{3}$ | A and B dist. much too small; estimated 1″·0. |
| | | | 302·0 | 21·22 | 6–12 | 87·246 | P. | $11\frac{1}{3}$ | A and C. β at Mount Hamilton 1879: A and B 250° ± 1″·0 ±. A and C 300° ± 12″·0 ± |
| β 757 | 7 8 23 | −36 21 | 67·7 | 2·57 | 6–9 | 87·227 | P. | $11\frac{1}{3}$ | A pretty double, but much wider than B makes it; est. dist. = 3″·0 ±. β at Mount Hamilton, 1879: 60° ± 1″·5 ±. |
| β 759 / h 5028 | 18 4 19 | −36 48 | 121·7 | 2·17 | 9–9·5 | 86·605 | P. | $7\frac{1}{4}$ | A and B } β at Mount Hamilton: A and B 118°·1 1″·20 /79·681. |
| | | | 148·7 | 15·27 | 9·9 | 86·605 | P. | $7\frac{1}{4}$ | A and C } A and C 149°·2 34″·81 /79·681. |
| β 760 | 18 9 55 | −36 48 | 99·5 | 4·36 | 3–11 | 86·712 | P. | $11\frac{1}{3}$ | A fine double with a distant companion, 10 mag. about 300° ±. Mean of β's measures is: Pos. 99°·9 Dist. 2″·85 1879·676. |
| β 761 | 19 31 49 | −40 0 | 198·7 | 2·55 | 7–11 | 86·712 | P. | $11\frac{1}{3}$ | Mean of β's measures is: Pos. 197°·4, Dist. 1″·92 1879·684. |
| β 763 | 20 16 8 | −42 50 | 31·0 | est. 0·7 | 7–8 | 86·605 | P. | $7\frac{1}{4}$ | β's measures are: Pos. 28°·6 Dist. 1″·23 1879·687. / 19°·9 1″·25 79·753. |
| β 766 | 21 17 9 | −41 30 | 302·0 | est. 0·5 | 6–7 | 86·706 | P. | $11\frac{1}{3}$ | Definition very bad. Mean of β's measures is: Pos. 314°·2 Dist. 0″·84 /79·727. |
| β 768 | 21 48 55 | −37 51 | | | | 86·605 | R. | $11\frac{1}{3}$ | A large star following γ Gruis examined with 800 and 1200, not divided, though it seems elongated in direction of motion; angle 90° ±. Only thought double by β. |
| β 767 | 21 19 48 | −43 3 | 146·3 | 3·47 | 6–9 | 86·602 | P. | $7\frac{1}{4}$ | Mean of β's measures are: Pos. 146°·1 Dist. 4″·05 /79·709. |

Dist. of A and C Sydney readings of micro. screw /86·605 are

| Revs. |
|---|
| 24·713 |
| 26·123 |
| 24·726 |
| 26·113 |

Coincidence found by direct measures 25·422.

26·1180
24·7195
1·3985 = double dist.
0·6993 = dist.

Value of screw = 21″·835 ∴ dist. = 15″·27.

## *Observations* of the Companion of Sirius made at the Dearborn Observatory, Chicago, U.S.A.* By Prof. G. W. Hough, Director.

(*Communicated by the Secretaries.*)

| Date. | Sid. Time. | p. | s. | Remarks. |
|---|---|---|---|---|
| | h | ° | ″ | |
| 1887·118 | 5·9 | 24·7 | — | High winds. Unsteady. |
| ·148 | 6·6 | 24·4 | 6·90 | Difficult. |
| ·186 | 7·5 | 23·7 | clouded | Comp. plain. |
| ·211 | 7·2 | 23·7 | 6·80 | Difficult. |
| ·217 | 7·5 | 23·2 | 6·77 | Comp. plain. Vis. with 925 power. |
| ·236 | 8·0 | 23·1 | 6·65 | Difficult. Clouds passing. |
| ·249 | 7·8 | 23·3 | 6·77 | Difficult. Hazy. |

Mean Results.

| | | | |
|---|---|---|---|
| 1887·195 | | 23·7 | 6·78 |

During the past spring the weather here has been very unfavourable. It is the first year that I have found any difficulty in securing observations of *Sirius* on as many nights as was desirable. The decrease in the distance, however, makes the observation of this pair more difficult every year, and hence requires better atmospheric conditions than formerly.

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## *On the Orbit of* Σ 1757. By J. E. Gore.

A reference to my paper on the orbit of this binary star in the *Monthly Notices* for November 1886 will show that the comparison between the measures of position angles in recent years and the angles computed from the elements there given is not satisfactory. I have re-computed the orbit, using recent measures kindly made for me by Mr. Tarrant and Prof. Young (U.S.A.), and now find the following elements:—

*Second Elements of* Σ 1757.

| | |
|---|---|
| $P = 276{\cdot}92$ years | $\Omega = 87° \; 36'$ |
| $T = 1791{\cdot}98$ A.D. | $\lambda = 185° \; 23'$ |
| $e = 0{\cdot}4498$ | $a = 2{\cdot}05''$ |
| $\gamma = 40° \; 56'$ | $\mu = +1{\cdot}30°$ |

The following is a comparison between the observations and the positions computed from the above elements:—

| Epoch. | Observer. | $\theta_c$ | $\theta_c$ | $\theta_o - \theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o - \rho_c$ |
|---|---|---|---|---|---|---|---|
| 1825·37 | Struve | 10·0 | 10·47 | −0·47 | 1·60 | 1·26 | +0·34 |
| 1829·82 | „ | 19·5 | 19·57 | −0·03 | 1·44 | 1·37 | +0·07 |
| 1832·39 | Smyth | 24·1 | 24·19 | −0·09 | 1·5 | 1·44 | +0·06 |
| 1833·38 | Struve | 23·9 | 25·83 | −1·93 | 1·54 | 1·46 | +0·08 |
| 1835·37 | „ | 25·5 | 29·03 | −3·53 | 1·66 | 1·51 | +0·15 |
| 1836·42 | „ | 29·4 | 30·67 | −1·27 | 1·64 | 1·53 | +0·11 |
| 1838·48 | Smyth | 31·0 | 33·62 | −2·62 | 1·7 | 1·58 | +0·12 |
| 1841·38 | Mädler | 36·0 | 37·48 | −1·48 | 1·74 | 1·66 | +0·08 |
| 1842·39 | Dawes | 37·4 | 38·72 | −1·32 | 1·67 | 1·69 | −0·02 |
| 1842·52 | Smyth | 37·9 | 38·89 | −0·99 | 1·7 | 1·69 | +0·01 |
| 1843·45 | Dawes | 38·8 | 40·00 | −1·2 | — | 1·70 | — |
| 1843·51 | Kaiser | 40·9 | 40·07 | +0·83 | — | 1·71 | — |
| 1844·72 | O. Struve | 43·7 | 41·50 | +2·20 | 1·89 | 1·74 | +0·15 |
| 1845·88 | Mädler | 40·8 | 42·77 | −1·97 | 2·02 | 1·77 | +0·25 |
| 1850·38 | O. Struve | 48·8 | 47·43 | +1·37 | 1·85 | 1·89 | −0·04 |
| 1852·38 | Smyth | 51·7 | 49.25 | +1·45 | 2·0 | 1·94 | +0·06 |
| 1853·09 | Mädler | 52·2 | 49·98 | +2·22 | 2·05 | 1·96 | +0·09 |
| 1853·73 | Jacob | 48·0 | 50·54 | −2·54 | 2·14 | 1·98 | +0·16 |
| 1854·37 | Mädler | 50·1 | 51·10 | −1·00 | 2·16 | 1·99 | +0·17 |
| 1855·31 | „ | 51·3 | 51·96 | −0·66 | 1·7 | 2·01 | −0·31 |
| 1856·32 | „ | 51·8 | 52·80 | −1·00 | 1·5 | 2·04 | −0·54 |
| 1856·42 | Morton | 51·9 | 52·89 | −1·01 | 2·01 | 2·04 | −0·03 |
| 1856·88 | Secchi | 52·9 | 53·27 | −0·37 | 1·84 | 2·05 | −0·21 |
| 1857·29 | Morton | 54·2 | 53·61 | +0·59 | 2·00 | 2·06 | −0·06 |
| 1858·08 | Jacob | 52·8 | 54·24 | −1·44 | 1·76 | 2·07 | −0·31 |
| 1858·37 | Mädler | 54·7 | 54·47 | +0·23 | 1·91 | 2·08 | −0·17 |
| 1859·36 | „ | 53·7 | 55·24 | −1·54 | 1·82 | 2·11 | −0·29 |
| 1860·34 | Dawes | 54·3 | 56·03 | −1·73 | 2·31 | 2·13 | +0·18 |
| 1860·35 | „ | 53·4 | 56·03 | −2·63 | 2·08 | 2·13 | +0·05 |
| 1863·32 | Dembowski | 59·0 | 58·23 | +0·77 | 2·01 | 2·20 | −0·19 |
| 1865·97 | „ | 60·4 | 60·06 | +0·34 | 2·09 | 2·25 | −0·16 |
| 1866·01 | O. Struve | 60·8 | 60·09 | +0·71 | 2·34 | 2·25 | +0·09 |
| 1867·27 | Talmage | 63·7 | 61·00 | +2·70 | 2·60 | 2·28 | +0·32 |
| 1868·30 | Dembowski | 62·7 | 61·65 | +1·05 | 2·04 | 2·30 | −0·26 |
| 1869·22 | Brünnow | 63·4 | 62·25 | +1·15 | 2·59 | 2·32 | +0·27 |
| 1869·24 | Talmage | 64·3 | 62·25 | +2·05 | — | 2·32 | — |
| 1870·15 | Dembowski | 63·5 | 62·87 | +0·63 | 2·03 | 2·34 | −0·31 |
| 1870·37 | Talmage | 64·1 | 63·00 | +1·10 | 2·00 | 2·34 | −0·34 |
| 1871·19 | Dembowski | 63·4 | 63·52 | −0·12 | 2·13 | 2·35 | −0·22 |

| Epoch. | Observer. | $\theta_o$ | $\theta_c$ | $\theta_o-\theta_c$ | $\rho_o$ | $\rho_c$ | $\rho_o-\rho_c$ |
|---|---|---|---|---|---|---|---|
| 1872·33 | Wilson & Seabroke | 64·8 | 64·25 | +0·55 | 2·30 | 2·37 | −0·07 |
| 1872·37 | Talmage | 67·3 | 64·27 | +3·03 | — | 2·37 | — |
| 1873·23 | Wilson & Seabroke | 64·0 | 64·80 | −0·80 | 2·05 | 2·38 | −0·33 |
| 1873·35 | " | 65·0 | 64·87 | +0·13 | 2·00 | 2·38 | −0·38 |
| 1874·32 | " | 65·5 | 65·45 | +0·05 | 2·15 | 2·40 | −0·25 |
| 1874·32 | Talmage | 69·8 | 65·45 | +4·35 | 1·08? | 2·40 | −1·32? |
| 1874·41 | Wilson & Seabroke | 64·2 | 65·50 | −1·30 | 2·16 | 2·40 | −0·24 |
| 1875·31 | Schiaparelli | 66·6 | 66·03 | +0·57 | 2·00 | 2·42 | −0·42 |
| 1876·36 | Wilson & Seabroke | 67·2 | 66·64 | +0·56 | 2·15 | 2·44 | −0·29 |
| 1876·41 | " | 66·5 | 66·67 | −0·17 | 2·21 | 2·45 | −0·24 |
| 1879·40 | Hall | 68·9 | 68·40 | +0·50 | 2·33 | 2·50 | −0·17 |
| 1879·470 | Schiaparelli | 67·98 | 68·40 | −0·42 | 2·462 | 2·50 | −0·038 |
| 1882·467 | " | 69·38 | 70·00 | −0·62 | 2·314 | 2·55 | −0·236 |
| 1883·21 | Engelmann | 70·44 | 70·43 | +0·01 | 2·623 | 2·56 | +0·063 |
| 1887·213 | Tarrant | 72·44 | 72·52 | −0·08 | 2·62 | 2·62 | 0·00 |
| 1887·356 | Young | 72·75 | 72·59 | +0·16 | 2·79 | 2·62 | +0·17 |

I have computed the following short ephemeris:—

| Date. | Position Angle. | Distance. |
|---|---|---|
| 1890·0 | 73·91° | 2·73″ |
| 1895·0 | 76·32 | 2·78 |
| 1900·0 | 78·64 | 2·83 |

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## *On the Formulæ for Correcting Approximate Elements of the Orbits of Binary Stars.* By A. Marth.

The present communication, a supplement of the paper in the April number of the *Monthly Notices*, pp. 333–46, is intended to point out the alterations and modifications of the formulæ there given, which render them applicable to the orbits of binary stars, and to offer some remarks connected therewith.

While in the case of the orbit of a satellite belonging to the solar system the apparent orbit, or the projection of the true orbit on a plane perpendicular to the line of vision, changes continually with the changing position of the Earth relative to the planet, in the case of a binary system the plane of projection remains unaltered, and may therefore properly be adopted as the plane to which the plane of the orbit is referred.

Let $\Omega_0$ denote the position-angle of the line of nodes of the two planes, reckoned from the declination-circle passing through the star at the time $t_0$, $\Omega$ the same angle reckoned from the declination-circle at the time $t$, so that

$$\Omega = \Omega_0 + 0^\circ{\cdot}00557 \sin \alpha \,.\, \sec \delta \,.\, (t - t_0).$$

Let $i$ be the inclination of the two planes, and let it be taken between 0° and 90°, if the apparent motion of the comes is in the direction of *in*creasing position-angles, and between 90° and 180°, if the motion is in the direction of *de*creasing position-angles, so that there may be no need to make a distinction between direct and retrograde motion in the orbit.

Further, let $\omega$ denote the angle between the node and the lower apsis in the direction of the real motion in the orbit; $e = \sin \phi$ the eccentricity; $a$ the major semi-axis of the orbit, expressed in seconds of arc; $a\rho$ the radius vector, $\mu$, $\epsilon$, $v$ the mean, eccentric, and true anomaly of the comes at the time $t$; $\mu_0$ its mean anomaly at the time $t_0$; $n$ its yearly mean orbital motion.

The true anomaly $v$ of the comes and its radius vector $\rho$, expressed in parts of $a$, being found by the usual formulæ

$$\epsilon - e^{\circ} . \sin \epsilon = \mu = \mu_0 + n(t - t_0) \qquad e^{\circ} = 57^{\circ}\cdot 296 . e,$$

$$\rho \sin v = \sin \epsilon . \cos \phi$$

$$\rho \cos v = \cos \epsilon - e,$$

the values of the position-angle $p$ and of the distance $s$ of the comes for the time $t$ are found by

$$\sin \sigma \sin (p - \Omega) = \sin (v + \omega) \cos i$$

$$\sin \sigma \cos (p - \Omega) = \cos (v + \omega)$$

$$s = a\rho . \sin \sigma.$$

Formulæ for correcting the assumed elements by means of equations of condition between observed and computed position-angles have been published by Mädler (*Astron. Nachr.*, vol. xvi. p. 36); also by Schur (*Astron. Nachr.*, vol. lxxi. p. 24), and perhaps in other papers, not at present within my reach. To be really efficient, such formulæ require that the assumed elements should be fairly approximate, but a rather wide field is left for their useful application. In the case of elements of questionable character, or even of first attempts, the formation of the equations of condition ought not to be neglected, for their mere aspect may prove to the computer the inadequacy of the observations at his disposal for a fair determination of the orbit; or if it does not prevent the publication of premature results of very doubtful value, it will at least prevent their undue acceptance by readers competent to form their own judgment.

Introducing for greater simplicity, as in the case of the orbit of a satellite belonging to the solar system—

$$\sin \sigma \sin \tau = + \cos i$$

$$\sin \sigma \cos \tau = - \sin i \cos (v + \omega)$$

$$\cos \sigma = + \sin i \sin (v + \omega),$$

the differentiation of the equations for $p$ and $s$ gives

$$\sin \sigma dp = \sin \tau \,.\, d(v+\omega) + \cos \tau \,.\, \sin(v+\omega) \,.\, di + \sin \sigma d\Omega$$
$$d\sigma = \cos \tau \,.\, d(v+\omega) - \sin \tau \,.\, \sin(v+\omega) \,.\, di.$$

If $e$ and $i$, eccentricity and inclination, are not of small amount, the equations of condition between the differences of the observed and computed position-angles and distances and the variations of the assumed elements will be

$$\begin{aligned}
\rho \sin \sigma \,.\, \delta p = & + \sin \tau \frac{\cos \phi}{\rho} \,.\, [\delta\mu_0 + (t-t_0)\delta n] \\
& + \rho \sin \tau \,.\, \delta\omega \\
& + \sin \tau (\sin v \cos \phi + \sin \epsilon) \,.\, \delta\phi \\
& + \rho \cos \tau \,.\, \sin(v+\omega) \,.\, \delta i \\
& + \rho \sin \sigma \,.\, \delta\Omega
\end{aligned}$$

$$\begin{aligned}
\frac{57 \cdot 3}{a} \,.\, \delta s = & + (\cos \sigma \cos \tau \,.\, \frac{\cos \phi}{\rho} + \tan \phi \sin \sigma \sin v) \,.\, (\delta\mu_0 + (t-t_0)\delta n) \\
& + \rho \cos \sigma \cos \tau \,.\, \delta\omega \\
& + [\cos \sigma \cos \tau (\sin v \cos \phi + \sin \epsilon) - \sin \sigma \cos v \cos \phi) \,.\, \delta\phi \\
& - \rho \cos \sigma \sin \tau \,.\, \sin(v+\omega) \,.\, \delta i \\
& + \rho \sin \sigma \,.\, \frac{57 \cdot 3}{a} \delta a.
\end{aligned}$$

In cases of moderate or small eccentricity it will be safer to substitute

$$\begin{aligned}
\rho \sin \sigma \,.\, \delta p = & + \sin \tau \,.\, (1 + e \cos v) \,.\, [\sec \phi \; \delta(\mu_0 + \omega) + (t-t_0) \,.\, \sec \phi \,.\, \delta n] \\
& - \sin \tau \,.\, (\cos v + \cos \epsilon \cos \phi + \tan \tfrac{1}{2}\phi) \,.\, 57 \cdot 3 \, (\tan \phi + \delta e) \sin \delta\omega \\
& + \sin \tau \,.\, (\sin v + \sin \epsilon \sec \phi) \,.\, 57 \cdot 3 \, [(\tan \phi + \delta e) \cos \delta\omega - \tan \phi] \\
& + \rho \cos \tau \,.\, \sin(v+\omega) \,.\, \delta i \\
& + \rho \sin \sigma \,.\, \delta\Omega
\end{aligned}$$

$$\begin{aligned}
\frac{57 \cdot 3}{a} \,.\, \delta s = & + [\cos \sigma \cos \tau \,.\, (1 + e \cos v) + e \sin \sigma \sin v] \, [\sec \phi \; \delta(\mu_0 + \omega) \\
& \qquad\qquad + (t-t_0) \sec \phi \,.\, \delta n] \\
& - [\cos \sigma \cos \tau \,.\, \cos v + \cos \epsilon \cos \phi + \tan \tfrac{1}{2}\phi) + \sin \sigma \sin v] \\
& \qquad\qquad \cdot 57 \cdot 3 \, (\tan \phi + \delta e) \sin \delta\omega \\
& + [\cos \sigma \cos \tau \,.\, (\sin v + \sin \epsilon \sec \phi) - \sin \sigma \cos v] \\
& \qquad\qquad \cdot 57 \cdot 3 \, [(\tan \phi + \delta e) \cos \delta\omega - \tan \phi] \\
& - \rho \cos \sigma \sin \tau \,.\, \sin(v+\omega) \,.\, \delta i \\
& + \rho \sin \sigma \,.\, \frac{57 \cdot 3}{a} \delta a.
\end{aligned}$$

If the assumed orbit is circular and the orbital longitude of the comes from the node is $= u$, the equations become

$$\begin{aligned}\sin\sigma\delta p = &+\sin\tau\,.\,[\delta u_0+(t-t_0)\,\delta n]\\ &-\sin\tau\,.\,\cos u\,.\,2\phi\sin\omega\\ &+\sin\tau\,.\,\sin u\,.\,2\phi\cos\omega\\ &+\cos\tau\,.\,\sin u\,.\,\delta i\\ &+\sin\sigma\,.\,\delta\Omega\\ \frac{57{\cdot}3}{a}\,\delta s = &+\cos\sigma\cos\tau\,[\delta u_0+(t-t_0)\,\delta n]\\ &-(\cos\sigma\cos\tau\,.\,\cos u+\tfrac{1}{2}\sin\sigma\,.\,\sin u)\,.\,2\phi\sin\omega\\ &+(\cos\sigma\cos\tau\,.\,\sin u+\tfrac{1}{2}\sin\sigma\,.\,\cos u)\,.\,2\phi\cos\omega\\ &-\cos\sigma\,.\,\sin\tau\,.\,\sin u\,.\,\delta i\\ &+\sin\sigma\,.\,\frac{57{\cdot}3}{a}\,\delta a.\end{aligned}$$

In case the inclination of the orbit to the plane of projection is not considerable, the determination of the line of nodes becomes uncertain, and this uncertainty develops with the decrease of inclination rapidly into indeterminateness. The uncertainty of fixing the position of the plane of the orbit may be easily estimated by the reflection that in order that the maximum effect of the inclination upon the position-angles may reach the amount of

$0^\circ{\cdot}5 \qquad 1^\circ{\cdot}0 \qquad 1^\circ{\cdot}5 \qquad 2^\circ{\cdot}0$

the inclination must amount to

$10^\circ{\cdot}7 \qquad 15^\circ{\cdot}1 \qquad 18^\circ{\cdot}4 \qquad 21^\circ{\cdot}2$

the corresponding maximum of the foreshortening of the radius vector being

0·017 ·034 ·051 0·067

or 1 : 58 29 20 15.

A fair determination of $\Omega$ and $i$ and consequently of $\omega$ being, under such circumstances, not practicable, they cannot serve directly as elements of the orbit, but ought to be supplanted by such functions or such other elements as will practically represent whatever can be fairly established concerning the position of the orbit, without erring either on the one side by a display of untrustworthy figures, or, on the other, by the assumption or suggestion of entire uncertainty.

The proper selection of the most suitable elements for the purpose does not appear to me doubtful. The choice will be different, according as the eccentricity of the orbit is considerable or not.

In case the orbit is so eccentric that the place of the chief star in the projected orbit is considerably distant from the centre,

the substitution of the position-angle P of the periastre for that of the line of nodes as an element recommends itself at once, and the selection of

$$\tan \nu = \frac{\sin^2 i \sin \omega \cos \omega}{1 - \sin^2 i \sin^2 \omega} \text{ and of } k = \frac{\cos i}{1 - \sin^2 i \sin^2 \omega}$$

as the two other new elements will be found a suitable one in the course of some simple considerations.

If in the equations for finding $p$ and $\sin \sigma$

$$\sin \sigma \sin (p - \Omega) = \sin (v + \omega) \cos i$$
$$\sin \sigma \cos (p - \Omega) = \cos (v + \omega)$$

the true anomaly $v$ is put $= 0°$, they supply the position-angle P of the periastre and the corresponding value of $\sin \sigma$, say $\sin \sigma_0$:

$$\sin \sigma_0 \sin (P - \Omega) = \sin \omega \cos i$$
$$\sin \sigma_0 \cos (P - \Omega) = \cos \omega$$

and thereby

$$\sin^2 \sigma_0 = 1 - \sin^2 i \sin^2 \omega.$$

The substitution of these values in the preceding equations gives

$$\sin \sigma_0 . \sin \sigma \sin (p - P) = \sin v . \cos i$$
$$\sin \sigma_0 . \sin \sigma \cos (p - P) = \cos v . (1 - \sin^2 i \sin^2 \omega) - \sin v . \sin^2 i \sin \omega \cos \omega$$

$$\text{or } \frac{\sin \sigma}{\sin \sigma_0} . \sin (p - P) = \sin v . \frac{\cos i}{1 - \sin^2 i \sin^2 \omega}$$

$$\frac{\sin \sigma}{\sin \sigma_0} . \cos (p - P) = \cos v - \sin v . \frac{\sin^2 i \sin \omega \cos \omega}{1 - \sin^2 i \sin^2 \omega}.$$

By the introduction of the position-angle

$$P = P_0 + 0°{\cdot}00557 \sin \alpha . \sec \delta . (t - t_0) \text{ of the periastre,}$$

and of

$$\frac{\cos i}{1 - \sin^2 i \sin^2 \omega} = k \text{ and } \frac{\sin^2 i . \sin \omega \cos \omega}{1 - \sin^2 i \sin^2 \omega} = \tan \nu$$

as the new elements, the equations for finding $p$ and $s$ become, if $(s)$ is written instead of

$$\frac{\rho \sin \sigma}{\sin \sigma_0}$$

and $(a)$ instead of $a \sin \sigma_0$ or $a \sqrt{1 - \sin^2 i \sin^2 \omega}$,

$$(s) \sin (p - P) = \rho \sin v . k \qquad = \sin \epsilon . k \cos \phi$$
$$(s) \cos (p - P) = \rho \cos v - \rho \sin v . \tan \nu = \cos \epsilon - \sin \epsilon . \tan \nu . \cos \phi - e$$
$$s = (a) . (s)$$

If the plane of the orbit coincides with the plane of projection, the value of $\tan \nu$ is $= 0$ and that of $k = +1$ or $-1$ according as the apparent motion of the comes is in the direction of in-

creasing or *de*creasing position-angles. The values of tan $\nu$ and of the deviation of $k$ from $\pm 1$, which a careful discussion of the observations furnishes, represent fully whatever the observations really indicate about the inclination of the two planes and its direction.

The differentiation of the last equations gives

$$(s)\,dp = \frac{k\rho}{(s)} \,.\, \rho dv + \rho \sin v \,.\, \cos(p-\mathrm{P}) \,.\, 57{\cdot}3\, dk$$
$$+ \rho \sin v \,.\, \sin(p-\mathrm{P}) \,.\, 57{\cdot}3\, d(\tan\nu) + (s)\, d\mathrm{P}$$

$$\frac{57{\cdot}3}{(a)} ds = \left(k^2 - \frac{\sin(v+\nu)\cos(v+\nu)}{\sin v \,.\, \cos v \,.\, \cos^2\nu}\right) . \frac{\rho \sin v \cos v}{(s)} \,.\, \rho dv + \frac{(s)}{\rho} \,.\, 57{\cdot}3 \,.\, d\rho$$
$$+ \rho \sin v \,.\, \sin(p-\mathrm{P}) \,.\, 57{\cdot}3\, dk - \rho \sin v \,.\, \cos(p-\mathrm{P}) \,.\, 57{\cdot}3\, d(\tan\nu)$$
$$+ (s)\, \frac{57{\cdot}3}{(a)} \,.\, d(a).$$

The equations of condition between variations of the computed coordinates and the corresponding variations of the elements of the orbit become accordingly:

$$(s)\, \delta p = \frac{k}{(s)} \,.\, \cos\phi\, [\delta\mu_0 + (t-t_0)\, \delta n]$$
$$+ \frac{\rho}{(s)} \,.\, (\sin v \cos\phi + \sin\epsilon) \,.\, \delta\phi$$
$$+ \rho \sin v \,.\, \cos(p-\mathrm{P}) \,.\, \delta k$$
$$+ \rho \sin v \,.\, \sin(p-\mathrm{P}) \,.\, \delta(\tan\nu)$$
$$+ (s) \,.\, \delta\mathrm{P}$$

$$\frac{57{\cdot}3}{(a)}\, \delta s = \left[\left(k^2 - \frac{\sin(v+\nu)\cos(v+\nu)}{\sin v \,.\, \cos v \,.\, \cos^2\nu}\right) \frac{\cos v \cos\phi}{(s)} + \tan\phi \,.\, \frac{(s)}{\rho}\right] \sin v$$
$$[\delta\mu_0 + (t-t_0)\, \delta n]$$
$$+ \left[\left(k^2 - \frac{\sin(v+\nu)\cos(v+\nu)}{\sin v \,.\, \cos v \,.\, \cos^2\nu}\right)(\sin v \cos\phi + \sin\epsilon) . \frac{\rho \sin v}{(s)}\right.$$
$$\left. - \cos\phi \,.\, \frac{(s)}{\rho}\right] \cos v \,.\, \delta\phi$$
$$+ \rho \sin v \,.\, \sin(p-\mathrm{P}) \,.\, \delta k$$
$$- \rho \sin v \,.\, \cos(p-\mathrm{P}) \,.\, \delta(\tan\nu)$$
$$+ (s)\, \frac{57{\cdot}3}{(a)} \,.\, \delta(a)$$

In case the eccentricity of the orbit is not large enough to allow the position-angle of the periastre to be safely treated as one of the elements, the most suitable new elements will be found by reckoning the orbital longitudes from the point of the orbit, for which $p = 0°$, or where the orbit crosses the plane of the declination circle to the north of the chief star. If $\omega'$ is the orbital longitude of the periastre reckoned from this point, or $-\omega'$ the true anomaly of this point, the values of $\omega'$ and of the correspond-

ing $\sin\sigma$, say $\sin\sigma'$, are derived from the equations, which give $p$ and $\sin\sigma$,

$$\sin\sigma\sin(p-\Omega)=\sin(v+\omega)\cos i$$
$$\sin\sigma\cos(p-\Omega)=\cos(v+\omega)$$

by putting

$$p=0^\circ \text{ and for } v \text{ its special value} -\omega'.$$

Thus are found

$$\sin\sigma'\sin\Omega=\sin(\omega'-\omega)\cos i$$
$$\sin\sigma'\cos\Omega=\cos(\omega'-\omega)$$
$$\sin^2\sigma'=1-\sin^2 i\sin(\omega'-\omega)\cos(\omega'-\omega).$$

The substitution of these values in the preceding or their equivalent equations

$$\sin\sigma\sin p=\sin(v+\omega)\cos i\cos\Omega+\cos(v+\omega)\sin\Omega$$
$$\sin\sigma\cos p=\cos(v+\omega)\cos\Omega-\sin(v+\omega)\cos i\sin\Omega$$

leads to the equations

$$\frac{\sin\sigma}{\sin\sigma'}.\sin p=\sin(v+\omega').\frac{\cos i}{1-\sin^2 i.\sin^2(\omega'-\omega)}$$
$$\frac{\sin\sigma}{\sin\sigma'}.\cos p=\cos(v+\omega')+\sin(v+\omega').\frac{\sin^2 i.\sin(\omega'-\omega)\cos(\omega'-\omega)}{1-\sin^2 i.\sin^2(\omega'-\omega)}.$$

By the introduction of $\omega'$ and of

$$\frac{\cos i}{1-\sin^2 i.\sin^2(\omega'-\omega)}=k' \text{ and } \frac{\sin^2 i.\sin(\omega'-\omega)\cos(\omega'-\omega)}{1-\sin^2 i.\sin^2(\omega'-\omega)}=\tan\nu',$$

as the new elements, which supplant $\Omega$, $\omega$, $i$, the equations for finding $p$ and $s$ become, if $(\sigma)$ is written instead of

$$\frac{\sin\sigma}{\sin\sigma'}$$

and $a'$ instead of $a\sin\sigma'$ or $a\sqrt{1-\sin^2 i.\sin^2(\omega'-\omega)}$,

$$(\sigma)\sin p=\sin(v+\omega').k'$$
$$(\sigma)\cos p=\cos(v+\omega')+\sin(v+\omega').\tan\nu'=\cos(v+\omega'-\nu')\sec\nu'$$
$$s=a'\rho(\sigma).$$

The differentiation of these equations gives

$$\rho(\sigma)dp=\frac{k'}{(\sigma)}.\rho\, d(v+\omega')+\rho\sin(v+\omega')\cos p.57{\cdot}3\, dk'$$
$$-\rho\sin(v+\omega')\sin p.57{\cdot}3\, d(\tan\nu')$$

$$\frac{57{\cdot}3}{a'}.ds=\left(k'^2-\frac{\sin(v+\omega'-\nu')\cos(v+\omega'-\nu')}{\sin(v+\omega')\cos(v+\omega')\cos^2\nu'}\right).\frac{\sin(v+\omega')\cos(v+\omega')}{(\sigma)}$$
$$\rho\, d(v+\omega')$$
$$+(\sigma).57{\cdot}3\, dp+\rho\sin(v+\omega')\sin p.57{\cdot}3\, dk'+\rho\sin(v+\omega')\cos p.57{\cdot}3\, d(\tan\nu')$$
$$+\rho(\sigma).\frac{57{\cdot}3}{a'}.da.$$

But

$$\rho d(v+\omega') = \frac{\cos\phi}{\rho} d(\mu+\omega') - (\cos v + \cos\epsilon\cos\phi + \tan\tfrac{1}{2}\phi) \, . \tan\phi d\omega'$$
$$+ (\sin v + \sin\epsilon\sec\phi) \, . \cos\phi d\phi$$

and

$$57{\cdot}3\, d\rho = \tan\phi\sin v\, d(\mu+\omega') - \sin v \, . \tan\phi d\omega' - \cos v \, . \cos\phi d\phi.$$

Hence the equations of condition will be

$$\begin{aligned}\rho(\sigma)\,\delta p = &+\frac{k'\cos\phi}{(\sigma)\rho} \, . \, [\delta(\mu_0+\omega') + (t-t_0)\,\delta n] \\ &-\frac{k'}{(\sigma)}(\cos v + \cos\epsilon\cos\phi + \tan\tfrac{1}{2}\phi) \, . \, 57{\cdot}3\,(\tan\phi+\delta e)\sin\delta\omega' \\ &+\frac{k'}{(\sigma)}(\sin v + \sin\epsilon\sec\phi) \, . \, 57{\cdot}3\,[(\tan\phi+\delta e)\cos\delta\omega' - \tan\phi] \\ &+\rho\sin(v+\omega')\cos p \, . \, 57{\cdot}3\,\delta k' \\ &-\rho\sin(v+\omega')\sin p \, . \, 57{\cdot}3\,\delta(\tan\nu')\end{aligned}$$

and, if $h$ is written instead of

$$k'^2\sin(v+\omega')\cos(v+\omega') - \sin(v+\omega'-\nu')\cos(v+\omega'-\nu')\sec^2\nu',$$

$$\begin{aligned}\frac{57{\cdot}3}{a'}\delta s = &+\left(\frac{h\cos\phi}{(\sigma)\rho} + (\sigma)\tan\phi\sin v\right) . \, [\delta(\mu_0+\omega') + (t-t_0)\delta n] \\ &-\left[\frac{h}{(\sigma)}(\cos v + \cos\epsilon\cos\phi + \tan\tfrac{1}{2}\phi) + (\sigma)\sin v\right] \\ &\qquad\qquad . \, 57{\cdot}3\,(\tan\phi+\delta e)\sin\delta\omega' \\ &+\left[\frac{h}{(\sigma)}(\sin v + \sin\epsilon\sec\phi) - (\sigma)\cos v\right] . \, 57{\cdot}3\,[(\tan\phi+\delta e)\cos\delta\omega' - \tan\phi] \\ &+\rho\sin(v+\omega')\sin p \, . \, 57{\cdot}3\,\delta k' \\ &+\rho\sin(v+\omega')\cos p \, . \, 57{\cdot}3\,\delta(\tan\nu') \\ &+\rho(\sigma) \, . \, \frac{57{\cdot}3}{a'} \, . \, \delta a'.\end{aligned}$$

If the assumed eccentricity is 0, and the orbital longitude of the comes, reckoned from the point of the orbit, for which $p = 0°$, is called $u'$, the equations for finding $p$ and $s$ become

$$\begin{aligned}(\sigma)\sin p &= \sin u' \, . \, k' \\ (\sigma)\cos p &= \cos u' + \sin u' \, . \, \tan\nu' = \cos(u'-\nu') \, . \, \sec\nu' \\ s &= a' \, . \, (\sigma)\end{aligned}$$

and the equations between the variations of the coordinates and the variations of the elements:

$$\begin{aligned}(\sigma)\,\delta p = &+\frac{k'}{(\sigma)} \, . \, [\delta u'_0 + (t-t_0)\,\delta n] \\ &-\frac{k'}{(\sigma)} \, . \, \cos u' \, . \, 2\phi\sin\omega' \\ &+\frac{k'}{(\sigma)} \, . \, \sin u' \, . \, 2\phi\cos\omega' \\ &+\sin u' \, . \, \cos p \, . \, 57{\cdot}3\,\delta k' \\ &-\sin u' \, . \, \sin p \, . \, 57{\cdot}3\,\delta(\tan\nu')\end{aligned}$$

and, if $h'$ is written instead of

$$k'^2 - \frac{\sin(u'-\nu')\cos(u'-\nu')}{\sin u' \cos u' \,.\, \cos^2\nu'},$$

$$\begin{aligned}\frac{57.3}{a'} \,.\, \delta s = &+\frac{h'}{(\sigma)} \,.\, \sin u' \cos u' \,.\, [\delta u'_0 + (t-t_0)\,\delta n] \\ &-\left(\frac{h'}{(\sigma)} \,.\, \cos^2 u' + \tfrac{1}{2}(\sigma)\right) \,.\, \sin u' \,.\, 2\phi \sin \omega' \\ &+\left(\frac{h'}{(\sigma)} \,.\, \sin^2 u' - \tfrac{1}{2}(\sigma)\right) \,.\, \cos u' \,.\, 2\phi \cos \omega' \\ &+\sin u' \,.\, \sin p \,.\, 57.3\, \delta k' \\ &+\sin u' \,.\, \cos p \,.\, 57.3\, \delta(\tan \nu') \\ &+(\sigma) \,.\, \frac{57.3}{a'} \,.\, \delta a'.\end{aligned}$$

The geometrical meaning and the mutual relations of the various arcs and angles employed will be easily recognised with the help of a diagram constructed to indicate their significance on a sphere which has the chief star of the binary system in the centre. Let E denote the astral position of the Earth (in right ascension $\alpha + 180°$ and declination $-\delta$); C that of the crossing point of the declination circle and of the circle representing the plane of projection; O that of the (positive) pole of the orbit, so that EO $= i$; ☊$'$ the position of the point of the orbit where it crosses the declination circle; ☊ that of the point where it crosses the plane of projection; P the position of the periastre; S that of the satellite when its true anomaly is $v$. Further, let $P_{,}$ be the point where the arc EP or its prolongation meets the circle of projection; and P$'$ and C$'$ the points where the arcs $OP_{,}$ and OC or their prolongations cross the orbit.

The various arcs and angles are

| | |
|---|---|
| $i$ = EO = O☊E | $p$ = CES |
| ☊ = C☊ = CE☊ | P = CEP |
| $\omega$ = ☊P = ☊OP | $\sigma$ = ES |
| $v$ = PS = POS | $\sigma_0$ = EP |
| $\nu$ = $P_{,}$P = P$'$OP | $\sigma'$ = E☊$'$ |
| $\omega'$ = ☊$'$P = ☊$'$OP | $\tau$ = ☊SE |
| $\nu'$ = ☊$'$C$'$ = ☊$'$OC$'$ | OEC = 90° − ☊ |
| $\omega' - \omega$ = ☊$'$☊ = ☊$'$O☊ | POE = 90° − $\omega$ |

The arcs between any point of the orbit and O, and between any point of the circle of projection and E, are, of course, all $= 90°$.

The values of $\omega$, $i$, ☊, $a$, corresponding to the values of $k$, $\tan \nu$, P, $(a)$, or of $k'$, $\tan \nu'$, $\omega'$, $a'$ may be found by means of the formulæ

$$\gamma \sin 2\omega = 2 \tan \nu \qquad \gamma' \sin 2(\omega' - \omega) = 2 \tan \nu'$$

$$\gamma \cos 2\omega = 1 - k^2 - \tan^2 \nu \qquad \gamma' \cos 2(\omega' - \omega) = 1 - k'^2 - \tan^2 \nu'$$

$$\sin^2 i = \frac{\gamma}{1 + \gamma \sin^2 \omega} \qquad \sin^2 i = \frac{\gamma'}{1 + \gamma' \sin^2 (\omega' - \omega)}$$

$$\sin \sigma_0 \sin (P - \Omega) = \sin \omega \cos i \qquad \sin \sigma' \sin \Omega = \sin (\omega' - \omega) \cos i$$

$$\sin \sigma_0 \cos (P - \Omega) = \cos \omega \qquad \sin \sigma' \cos \Omega = \cos (\omega' - \omega)$$

$$a = \frac{(a)}{\sin \sigma_0} \qquad a = \frac{a'}{\sin \sigma'}.$$

If $k \mp 1$ and $\tan \nu$ or $k' \mp 1$ and $\tan \nu'$ are of small amount, small variations of their values produce obviously large variations in the corresponding values of $\omega$, $i$, $\Omega$. The uncertainty in which semicircle $\omega$, $\omega'$, $\Omega$ are to be taken arises, of course, from the uncertainty which part of the true orbit is on the positive side of the plane of projection or in front of it. If the apparent motion of the comes in the direction of *in*creasing or *de*creasing position-angles is to be treated as analogous to direct or retrograde motion of the bodies of our solar system in reference to the ecliptic, the Earth is at the positive pole of the plane of projection, and the ascending node $\Omega$ ought to be where the comes passes from the further or negative side of the plane of projection to the positive side or to that from which the observations are taken. The uncertainty whether the position-angle $\Omega$ belongs to the ascending or descending node must be allowed for in transferring the position of the orbit from the plane of projection to a plane parallel to the terrestrial equator, or to some other fundamental plane. If J denotes the inclination of the plane of the orbit to that of the equator, N the longitude or right ascension of the ascending node, and Q the orbital longitude of the periastre reckoned from N, the values of J, N, Q are derived from those of $i$, $\Omega$, $\omega$, and of $\alpha$, $\delta$, the right ascension and declination of the star, by means of the formulæ

$$\begin{aligned}
\sin J \sin (\alpha - N) &= \pm \sin \Omega \sin i \sin \delta + \cos i \cos \delta \\
\sin J \cos (\alpha - N) &= \pm \cos \Omega \cos i \\
\sin J \sin (Q - \omega) &= \pm \cos \Omega \cos \delta \\
\sin J \cos (Q - \omega) &= \mp \sin \Omega \cos \delta \cos i - \sin \delta \sin i \\
\cos J &= \pm \sin \Omega \cos \delta \sin i - \sin \delta \cos i
\end{aligned}$$

or by equivalent formulæ, the upper or lower signs being valid according as the value of $\Omega$ refers to the ascending or descending node of the orbit on the plane of projection.

The apparent orbit of the comes may be laid down in the ordinary way by employing the semiaxes $a$ and $\beta$ of the apparent ellipse and their position-angle $\theta$ deduced from the elements. If $\Pi$ is the position-angle of the centre of the apparent ellipse at

the place of the chief star, and S its distance, the values of Π, S, $\theta$, $a$, $\beta$ may be found by the formulæ

$$S \sin (\Pi - \Omega) = -ae \,.\, \sin \omega \cos i$$
$$S \cos (\Pi - \Omega) = -ae \,.\, \cos \omega$$
$$(\alpha^2 - \beta^2) \sin 2 (\theta - \Omega) = S^2 \,.\, \sin 2 (\Pi - \Omega) = a^2 e^2 \,.\, \sin 2 \omega \cos i$$
$$(\alpha^2 - \beta^2) \cos 2 (\theta - \Omega) = S^2 \,.\, \cos 2 (\Pi - \Omega) + a^2 \cos^2 \phi \,.\, \sin^2 i$$
$$= a^2 e^2 \,.\, \cos 2 \omega + a^2 \sin^2 i \,(1 - e^2 \cos^2 \omega)$$
$$\alpha^2 + \beta^2 = S^2 + a^2 \cos^2 \phi \,(1 + \cos^2 i) = 2a^2 - a^2 e^2 - a^2 \sin^2 i \,(1 - e^2 \cos^2 \omega).$$

It will, however, be found more instructive to compute the apparent positions corresponding to a number of points of the true orbit, and to lay them down, together with the terminal points of the axes of the apparent ellipse, which may serve in drawing the latter. The eccentric anomalies $\epsilon$ in the true orbit which give the terminal points of the axes of the apparent orbit may be found from the equation

$$\tan 2\epsilon = \frac{-\sin 2\omega \,.\, \cos \phi}{\cos 2\omega - e^2 \cos^2 \omega + e^2 \,.\, \operatorname{cosec}^2 i};$$

or, in case $k$ and $\tan \nu$ are the given elements, from

$$\tan 2\epsilon = \frac{2 \tan \nu \sec \phi}{k^2 + \tan^2 \nu - \sec^2 \phi};$$

or, if $k'$ and $\tan \nu'$ are given, from

$$\tan 2\epsilon = -\cos \phi \,.\, \frac{(k' \cos \nu')^2 \sin 2\omega' - \sin 2(\omega' - \nu')}{(k' \cos \nu')^2 \cos 2\omega' - \cos 2(\omega' - \nu') + e^2[(k' \cos \nu')^2 \cos^2 \omega' - \sin^2 (\omega' - \nu')]}.$$

The minima and maxima of the apparent distance of the two stars, and consequently the points of the greatest and least change of position-angle, may be found most conveniently by determining the true anomalies $v$, which satisfy the equation

$$\frac{\sin 2(v + \omega)}{\sin (v + \omega - \omega_1)} = 2e \operatorname{cotg}^2 i \,.\, \frac{\cos \omega}{\cos \omega_1},$$

in which $\tan \omega_1 = \tan \omega \,.\, \sec^2 i$, and which is to be solved indirectly.

This is a biquadratic equation, and, when developed, takes probably its simplest form if $\tan \frac{1}{2} (v + \omega)$ is made the unknown quantity. When written out in full the equation becomes

$$\tan^4 \tfrac{1}{2}(v + \omega) + \frac{2 \cos^2 i}{e \sin \omega} \,.\, (e \cos \omega + \tan^2 i) \,.\, \tan^3 \tfrac{1}{2}(v + \omega)$$
$$+ \frac{2 \cos^2 i}{e \sin \omega} \,.\, (e \cos \omega - \tan^2 i) \,.\, \tan \tfrac{1}{2}(v + \omega) - 1 = 0,$$

and the coefficients show that of the four roots of the equation

two are imaginary, or else that all four roots are real, according as the values of the two terms

$$e \cos \omega + \tan^2 i \text{ and } e \cos \omega - \tan^2 i$$

have the same or opposite signs.

This biquadratic equation is identical with the equation which determines the minima and maxima of the $x$ ordinates of those instructive curves, the "ecliptical intersects" of the orbits of planets and comets, which, as I have explained in vol. xlv. of the *Monthly Notices*, will be found very serviceable in recognising the chief peculiarities and mutual relations of the orbits, and especially helpful in solving the problem of their proximities, provided, of course, that they are accompanied by the data necessary for the purpose. If there are no imaginary roots of the equation, so that there are two minima and maxima, the intersects become specially characteristic, as is the case with those of many cometary orbits, a few instances of which may be recognised on the reduced specimen plates published in vol. xlv.

If, instead of $\omega$ and $i$, $k$ and $\tan \nu$ are the given elements, the equation for finding the true anomalies $v$, which furnish the points of min. and max. distance from the chief star in the apparent orbit, will be

$$0 = (k^2 + \tan^2 \nu - 1) \sin 2v - 2 \tan \nu \cos 2v + 2e[(k^2 + \tan^2 \nu) \sin v - \tan \nu \cos v];$$

or, putting

$$g \sin G = -2 \tan \nu,$$
$$g \cos G = k^2 + \tan^2 \nu - 1,$$
$$h \sin H = -\tan \nu,$$
$$h \cos H = k^2 + \tan^2 \nu,$$
$$\frac{\sin(2v + G)}{\sin(v + H)} = -2e \cdot \frac{h}{g},$$

which is to be solved indirectly.

If $\omega'$, $k'$, $\tan \nu'$ are the given elements, the corresponding formulæ are

$$g' \sin G' = 2 \tan \nu',$$
$$g' \cos G' = k'^2 + \tan^2 \nu' - 1,$$
$$h' \sin H' = -\sin(\omega' - \nu') \sec \nu',$$
$$h' \cos H' = k'^2 \cos \omega' - \sin \nu' . \sin(\omega' - \nu'),$$
$$\frac{\sin[2(v + \omega') + G']}{\sin(v + \omega' + H')} = -2e \cdot \frac{h'}{g'}.$$

A special case still requires to be considered—the case in which one of the components of a binary system is invisible or unobserved, so that the orbit of the visible component round the centre of gravity of the system has to be determined from its observed right ascensions and declinations referred to those of other stars. The prospect of a fair determination must remain unpromising if the observations do not extend at

least over a full revolution, so that an approximate value of the period, or of the annual motion $n$, may be inferred with some confidence. If $n$, $e$, $\mu_0$, $\omega'$, $a'$, $k'$, $\nu'$ are the seven elements of the orbit, the rectangular coordinates of the visible star (in right ascension $\alpha$ and declination $\delta$) referred to the centre of gravity (in right ascension A and declination D) and to the circle of declination, are given by the equations

$$15 \cos \delta (\alpha - A) = s \sin p = a'k' . \rho \sin (v + \omega')$$
$$\delta - D = s \cos p = a' \sec \nu' . \rho \cos (v + \omega' - \nu').$$

The values of $\alpha$ and $\delta$ are therefore

$$\alpha = A + \frac{a'k'}{15 \cos \delta} . \rho \sin (v + \omega')$$
$$\delta = D + a' \sec \nu' . \rho \cos (v + \omega' - \nu').$$

Introducing the eccentric anomaly $\epsilon$, instead of the true anomaly $v$, and putting

$$\kappa_1 \sin \omega_1 = a'k' . \sin \omega'$$
$$\kappa_1 \cos \omega_1 = a'k' . \cos \omega' \cos \phi$$
$$\kappa^s = \frac{\kappa_1}{15 \cos \delta}$$

and

$$\kappa_2 \sin \omega_2 = a' \sec \nu' . \sin (\omega' - \nu') \cos \phi$$
$$\kappa_2 \cos \omega_2 = a' \sec \nu' . \cos (\omega' - \nu'),$$

the values of $\alpha$ and $\delta$ become

$$\alpha = A - e . \kappa^s \sin \omega_1 + \kappa^s . \sin (\epsilon + \omega_1)$$
$$\delta = D^2 - e . \kappa_2 \cos \omega_2 + \kappa_2 . \cos (\epsilon + \omega_2),$$

and show that of the seven elements or functions of elements of the orbit only five ($n$, $\mu_0$, $e$; $\kappa^s \sin \omega_1$, $\kappa^s \cos \omega_1$) can be determined from observed right ascensions alone, and five ($n$, $\mu_0$, $e$; $\kappa_2 \sin \omega_1$, $\kappa_2 \cos \omega_2$) from declinations alone.

The first approximate values of the unknown quantities may be got by deducing from the observations the maxima and minima of the rectangular coordinates, with the times corresponding to them, and also the times when the coordinates, in reference to some approximate values of A and D, are o. If, in the case of observed right ascensions, $\tau$ and $\tau_1$ are these latter times, and $\theta$ and $\theta_1$ the times of max. and min. of $\alpha - A$, approximate values of the unknown quantities are derived from

$$2e^\circ \sin \omega_1 = 180^\circ - (\tau_1 - \tau) n$$
$$2e^\circ \cos \omega_1 = (\theta_1 - \theta) n - 180^\circ$$
$$\text{max.} - \text{min.} = 2\kappa^s$$
$$\text{max.} + \text{min.} = 2 (\delta A - e . \kappa^s \sin \omega_1) = 2c^s,$$

and the mean anomaly at the time $\tau$ will be

$$= -\omega_1 + e^\circ \sin \omega_1.$$

If, in the case of observed declinations, $\theta'$ and $\theta'_1$ are the times of the max. and min. of $\delta - D$, and $\tau'$ and $\tau'_1$ the times when the difference is 0, so that the four times follow in the order $\theta'$, $\tau'$, $\theta'_1$, $\tau'_1$, approximate values of the unknown quantities are got from

$$2e^\circ \sin \omega_2 = 180^\circ - (\theta'_1 - \theta')\,n$$

$$2e^\circ \cos \omega_2 = (\tau'_1 - \tau')\,n - 180^\circ$$

$$\text{max.}' - \text{min.}' = 2\kappa_2$$

$$\text{max.}' + \text{min.}' = 2\,(\delta D - e\,.\,\kappa_2 \cos \omega_2) = 2c_2$$

and the mean anomaly at the time $\tau'$ will be

$$= 90^\circ - \omega_2 - e^\circ \cos \omega_2.$$

As the observed right ascensions alone leave it uncertain whether $k'$ and consequently $\kappa^a$ is positive or negative, proper circumspection must be exercised to settle the point with the help of the observations in declination; and, if required, 180° must be added to the deduced value of $\omega_1$, so that the longitudes in the orbit may be reckoned from the point where the orbit crosses the declination circle on the north side of the centre of gravity.

The formulæ for correcting assumed approximate values of the elements or functions of elements are, if the observations in both coordinates are treated separately:

$$\begin{aligned}
\delta(\alpha - A) = {} & + \frac{\cos(\epsilon + \omega_1)}{1 - e\cos\epsilon}\,.\,\frac{\kappa^a}{57\,3}[\delta\mu_0 + (t - t_0)\,\delta n] \\
& + \frac{\cos(\epsilon + \omega_1)}{1 - e\cos\epsilon}\,.\,\sin\epsilon\,.\,\kappa^a\delta e \\
& + \cos\epsilon\,.\,\delta(\kappa^a \sin\omega_1) \\
& + \sin\epsilon\,.\,\delta(\kappa^a \cos\omega_1) + \delta c^a \ldots \\
\delta(\delta - D) = {} & - \frac{\sin(\epsilon + \omega_2)}{1 - e\cos\epsilon}\,.\,\frac{\kappa_2}{57{\cdot}3}[\delta\mu_0 + (t - t_0)\delta n] \\
& - \frac{\sin(\epsilon + \omega_2)}{1 - e\cos\epsilon}\,.\,\kappa_2\delta e \\
& - \sin\epsilon\,.\,\delta(\kappa_2 \sin\omega_2) \\
& + \cos\epsilon\,.\,\delta(\kappa_2 \cos\omega_2) + \delta c_2 \ldots
\end{aligned}$$

The two series of results have three unknown quantities, $\delta\mu_0$, $\delta n$, $\delta e$, in common, the most probable values of which must be found by properly combining the equations of the two series.

From the values of the other quantities are found

$$a'k'\,.\,\sin\omega' = 15\cos\delta\,.\,\kappa^a \sin\omega_1$$

$$a'k'\,.\,\cos\omega' = 15\cos\delta\,.\,\kappa^a \cos\omega_1\,.\,\sec\phi$$

and

$$a'\sec\nu'\,.\,\sin(\omega' - \nu') = \kappa_2 \sin\omega_2\,.\,\sec\phi$$

$$a'\sec\nu'\,.\,\cos(\omega' - \nu') = \kappa_2 \cos\omega_2.$$

If the eccentricity of the orbit is not large enough to allow $\delta\mu_0$ to be made directly one of the unknown quantities, and it is preferred to treat $\omega'$ $a'$, $k'$, $\tan\nu'$ directly as the elements, and to determine the coordinates by

$$15\cos\delta\,.\,(\alpha-\mathrm{A})=x=a'k'\,.\,\rho\sin(v+\omega')$$
$$\delta-\mathrm{D}=y=a'\,.\,\rho\cos(v+\omega')+a'\,.\,\rho\sin(v+\omega')\,.\,\tan\nu'$$
$$=a'\sec\nu'\,.\,\rho\cos(v+\omega'-\nu'),$$

the equations of condition between the differences of the observed and computed coordinates and the corresponding variations of the elements become

$$\begin{aligned}\delta x = &+[\cos(v+\omega')+e\cos\omega']\,.\,k'\,.\,\frac{a'\sec\phi}{57\cdot 3}[\delta(\mu_0+\omega')+(t-t_0)\delta n]\\ &-[\cos(v+\omega')(\cos\epsilon\,.\,\cos\phi+\tan\tfrac{1}{2}\phi)+\cos\omega']\,.\,k'\,.\,a'(\tan\phi+\delta e)\sin\delta\omega'\\ &+[\cos(v+\omega')\sin\epsilon-\sin\omega'\cos\phi]\,.\,k'\,.\,a'[(\tan\phi+\delta\epsilon)\cos\delta\omega'-\tan\phi]\\ &+\frac{x}{a'k'}\,.\,\delta(a'k')+15\cos\delta\,.\,\delta\mathrm{A}\ldots\end{aligned}$$

$$\begin{aligned}\delta y = &-[\sin(v+\omega'-\nu')+e\sin(\omega'-\nu')]\sec\nu'\,.\,\frac{a'\sec\phi}{57\cdot 3}[\delta(\mu_0+\omega')+(t-t_0)\delta n]\\ &+[\sin(v+\omega'-\nu')(\cos\epsilon\,.\,\cos\phi+\tan\tfrac{1}{2}\phi)+\sin(\omega'-\nu')]\,.\,\sec\nu'\\ &\qquad .\,a'(\tan\phi+\delta e)\sin\delta\omega'\\ &-[\sin(v+\omega'-\nu')\sin\epsilon+\cos(\omega'-\nu')\cos\phi]\,.\,\sec\nu'\\ &\qquad .\,a'[(\tan\phi+\delta e)\cos\delta\omega'-\tan\phi]\\ &+\rho\sin(v+\omega')\,.\,a'\,\delta(\tan\nu')\\ &+\frac{y}{a'}\,.\,\delta a'+\delta\mathrm{D}\ldots\end{aligned}$$

from which the most probable values of the corrections are to be deduced. The elements $\omega$, $i$, $\Omega$ are then found by the formulæ previously given.

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*Observations of Nova Cygni, of some of the Planets, and of Comet Barnard, made at Mr. Wigglesworth's Observatory with the 15·5-inch Cooke Equatorial.* By J. G. Lohse.

*Nova Cygni.*

1885, Sept. 1.—*Nova Cygni* is of the same brightness as the small star of the 15th magnitude north preceding of it. No change in the brightness of the other stars, which were all seen, could be made out.

Oct. 3.—*Nova Cygni* was examined with a magnifying power of 260. It has become a little brighter, and is only 0·3 mag.

fainter than the stars Nos. 68 * and 73. The star No. 68 is a little brighter than No. 73, but the difference is scarcely 0·1 mag. *Nova Cygni* is not so well defined as the comparison stars, and is certainly surrounded by nebulosity. Attempts were made to see *Nova Cygni* with a McClean prism held in front of the eyepiece, but no trace of light could be recognised. The spectrum of the other three stars, forming with *Nova* a trapezium, could be seen without much difficulty, especially that of the 11th magnitude star No. 60.

Oct. 7.—*Nova Cygni* is of a bluish colour and surrounded by nebulosity. It is more than double as bright as the star No 50, and about of the same brightness with Nos. 68 and 73 No. 68 is a little brighter than No. 73.

Oct. 26.—*Nova Cygni* was examined with magnifying powers of 330 and 130. It is decidedly surrounded by nebulosity, and about 0·3 mag. fainter than the stars Nos. 68 and 73. No. 73 is nearly 0·1 mag. brighter than No. 68. No. 50 was very well seen, but it has not half the light of *Nova Cygni.*

Dec. 1.—*Nova Cygni* is 0·3 magnitude smaller than stars Nos. 68 and 73. Definition poor.

1886, May 1.—*Nova Cygni* is of the 14·5 magnitude. No change amongst the neighbouring stars was noticed.

July 5.—*Nova Cygni* is of the 14th magnitude, and nebulous in appearance.

July 22.—*Nova Cygni* is equal in brightness to star No. 73, and 0·2 mag. fainter than No. 68. *Nova* appears nebulous. The 15th mag. companion of *Nova* was also seen.

Aug. 2.—*Nova Cygni* is equal in brightness to stars Nos. 68 and 73. The 15th mag. star near it was very well seen.

The estimations indicate a small increase in the brightness of *Nova* during October, and it seems that one of the comparison stars is variable to a very small extent.

### *Venus.*

On January 2 and February 3, 1886, the dark part of *Venus* was distinctly seen by Mr. Wigglesworth and Mr. Lohse; it is of a gray colour, except near the terminator, where the secondary spectrum causes it to appear blue, and compared with the bright part of *Venus* it looks very much smaller. On January 2, from $5^h\ 15^m$ to $5^h\ 35^m$ G.M.T., when the definition was very good, the upper or south horn appeared rounded while the lower one was quite sharp. In prolongation of the lower horn, but perfectly separated from it, was a bright narrow line of light about $\frac{1}{20}$ of the diameter of *Venus* in length. A similar phenomenon is often presented by the mountains of the Moon near the south horn, which appear along the edge as a detached irregular line of light as long as the summits only are illuminated.

* *Copernicus*, vol. ii. p. 118.

## *Mars.*

During the opposition of 1886 the white spots near the poles of *Mars* were very small. On April 23, $10^h$ $38^m$ G.M.T., both white spots were very well seen; the northern spot was brighter than the southern one, but in size they were about equal. The diameter of the spots was estimated to be $\frac{3}{4}''$. On April 26, $9^h$ G.M.T., the northern white spot was very well seen; it seemed larger than on April 23, but the southern white spot was certainly not visible at the time.

## *Saturn.*

1885, Nov. 17.—The globe extends at the top beyond Cassini's division, and encroaches on the outer ring to the extent of a quarter to one-third of the breadth of the latter. Encke's division was seen in the ansæ four-tenths of the breadth of the outer ring from Cassini's division.

Nov. 18.—Encke's division was seen in the same position, and the globe's shadow on the crape ring was noticed distinctly. Definition good.

Dec. 2, $13^h$ $45^m$ G.M.T.—*Mimas* was seen distinctly in elongation on the following side. *Saturn* was not artificially obscured at the time nor moved out of the field. Encke's division was plainly seen in both ansæ nearly in the middle of the ring.

Dec. 26.—There is a northern and a southern belt and a dark polar cap on *Saturn*. The brown copper colour of the globe was very strongly shown. Encke's division was seen, and dark parallel lines on the inner side of the ansæ of the inner bright ring.

1886, Jan. 2.—The polar cap is darker than the south belt.

Feb. 3.—Encke's division was very well seen by Mr. Wigglesworth and Mr. Lohse.

March 25.—*Saturn* was very well seen. Encke's division could be traced very nearly right round, when the definition was at its best. The division is two-fifths from the outer edge and three-fifths from Cassini's division. At $8^h$ $2^m$ G.M.T., Mr. Wigglesworth saw *Mimas* in southern conjunction. Mr. Lohse tried to see it as well, but could not do so with certainty. The southern and northern dark belts showed very well, and the globe was plainly visible through the crape ring. Mr. Wigglesworth observed a faint narrow dark marking in the middle of the bright equatorial zone.

The dimensions of *Saturn* were measured 1885, Dec. 26, and 1886, Jan. 2, and the following are the mean results reduced to mean distance ($\log = 0{\cdot}97950$):

| | |
|---|---|
| Exterior diameter of outer ring (A) | $40''.95$ |
| Interior „ „ „ | $35.53$ |
| Exterior diameter of inner ring (B) | $34.38$ |
| Interior „ „ „ | $25.55$ |
| „ „ of crape ring (C) | $20.97$ |
| Equatorial „ of globe | $18.57$ |

On Jan. 2 the following quantities were also measured, and reduced to mean distance give

| | |
|---|---|
| Polar diameter of outer ring (A) | $19''.06$ |
| Distance of south pole from south limb | $1.81$ |
| „ „ belt „ north „ | $8.14$ |

Considering the equator coincident with the plane of the rings, the south belt would be situated in $25°.8$ south kronocentric latitude.

*Neptune.*

The following observations of the satellite of *Neptune* were made. The satellite was always very faint; it was estimated to be of the 14th magnitude.

| Date. | Greenwich M. T. h m | Position. ° | Distance. '' |
|---|---|---|---|
| 1885, Dec. 2 | 12 48 | 41.71 | 17.62 |
| 1886, Nov. 2 | 14 19.5 | 40.78 | 16.71 |
| 4 | 14 49 | 247.88 | 14.14 |

*Observations of Comet Barnard made at Mr. Wigglesworth's Observatory with the 15·5-inch Cooke Equatorial.*

| Date. 1887. | Greenwich Mean Time. | ☄ – * Δα | ☄ – * Δδ | α ☄ | δ ☄ | Comparisons. |
|---|---|---|---|---|---|---|
| | h m s | m s s | ′ ″ ″ | h m s | ° ′ ″ | |
| May 20 | 11 21 23 | +1 8·18 ± ·09 | +5 51·6 ± ·8 | 15 23 50·68 | −26 6 59·7 | 6, 6 |
| 21 | 12 22 42 | − 42·55 ± ·09 | − 59·2 ± ·8 | 15 25 42·86 | −25 25 58·7 | 4, 4 |
| 29 | 12 43 41 | −5 43·99 ± ·10 | +9 50·6 ± 1·2 | 15 41 4·60 | −19 39 51·6 | 3, 3 |

*Adopted Mean Places of Comparison Stars for 1887·0.*

| | α | Reduction. | δ | Reduction. | Authority. |
|---|---|---|---|---|---|
| | h m s | s | ° ′ ″ | ″ | |
| May 20 | 15 22 40·33 | +2·17 | −26 12 49·9 | −1·4 | Star connected with Yarnall 6419 |
| 21 | 15 26 23·26 | +2·15 | −25 24 58·3 | −1·2 | „ „ „ 6405 |
| 29 | 15 46 46·47 | +2·12 | −19 49 42·3 | +0·1 | Yarnall 6543 |

The comet has a nucleus, but is faint and small. The observations are corrected for refraction.

*Mr. Wigglesworth's Observatory, Scarborough:*
1887, *June* 8.

## *The Solar Corona, as shown in Photographs taken during Total Eclipses.* By W. H. Wesley.

(*Communicated by the Secretaries.*)

Having had occasion to make a very minute examination of the negatives taken during several of the recent solar eclipses, I have thought that it might be of interest to give an account of some of the prominent features of the photographic corona in the different years. I do not attempt to propound any theories, and shall only mention some of the current hypotheses with a view of showing how far they appear to be supported or contradicted by the photographic records.

Mr. Ranyard in the eclipse volume of the *Memoirs* has so fully discussed the photographs taken previously to 1878, that in most cases it will only be necessary very briefly to allude to them.

One of the most striking features in the corona of almost all the years under examination is the existence of a more or less well-marked polar rift, roughly, but perhaps never exactly, corresponding with the Sun's axis of rotation, to which it appears sometimes inclined as much as 30°. In most cases this rift is shown at both poles, but sometimes at one only; in 1882 it does not appear at all. The northern and southern rifts are seldom strictly opposite to one another, so that a line drawn through them does not pass through the centre of the Sun. The polar rifts are generally filled with shorter, straighter, and more radial rays, with a background of less density than in other parts of the corona.

On either side of the polar rift there usually appears a somewhat conical mass, composed of rays curving towards each other, forming groups of what Mr. Ranyard has appropriately called "synclinal structure," which give the quadrilateral or cruciform appearance frequently shown in corona drawings. They mostly seem to be situated over the zones of maximum sunspot activity, and have frequently greater extension than other parts of the corona.

### *Eclipse of* 1851, *July* 28.

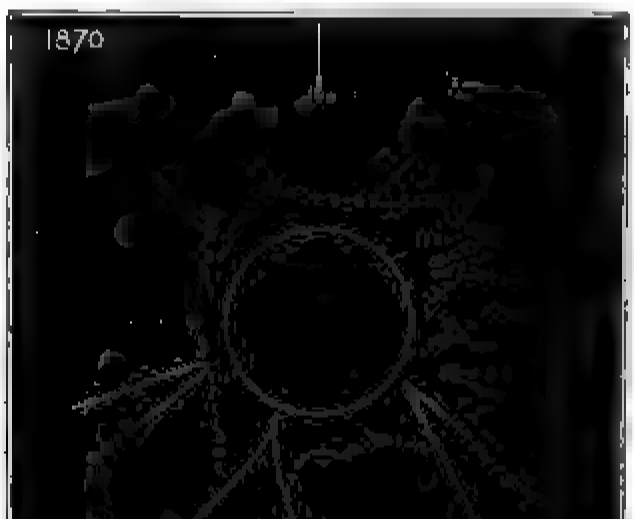
Dr. Busch's daguerreotype is remarkable as the first instance of a successful photograph of the corona. It shows the general form to a height nowhere much exceeding $\frac{1}{4}$ of a solar diameter. The corona is symmetrical and of hexagonal form, with a well-marked rift not far from the north and south poles, the southern rift being much the broader. On either side of these rifts are indications of synclinal masses; there are also similar masses in the equatorial regions fairly corresponding on each side. The orientation of the plate is rather uncertain. Wolf gives 64·2 as the relative number of sunspots for July 1851.


*Eclipse of* 1860, *July* 18.

In the photographs taken at Desierto de las Palmas, of which I have only seen positive copies, there is shown a very broad rift towards the south pole, and a less marked one on the north. The character of the synclinal groups is not clearly marked. The corona is fairly symmetrical about a line not much inclined from the Sun's axis. Wolf's relative number of sunspots is 94·9.

*Eclipse of* 1869, *August* 7.

I have not seen the original negatives of the photographs taken at Shelbyville, which are the only ones which show any considerable extent of corona. The northern and southern polar rifts are clearly marked and very broad. The bases of the four synclinal groups can also be clearly made out, especially that in the north-west quadrant. The general axis of symmetry is slightly inclined to the north-west and south-east of the Sun's axis. Wolf's relative number of sunspots is 77·6.




*Eclipse of* 1870, *Dec.* 22.

Mr. Brothers's negative, taken at Syracuse, shows a great extent of corona, reaching in some parts quite 40′ from the limb.

The general outline is somewhat circular, with a quadrilateral area of greater brightness, brighter on the western side. The northern polar rift is broad and ill-defined; to the east of the south pole is a much narrower and more sharply defined rift, easily traceable to the limb. To the east and west of this are other rifts, and there is structure evidently synclinal to the north-west; otherwise the photograph shows but little detail. The general axis of symmetry appears inclined to the north-west and south-east of the Sun's axis as much as 20°, but the orientation is not very certain. The eclipse occurred at a period of great solar activity, Wolf's relative monthly number being 135·4


*Eclipse of* 1871, *Dec.* 12.

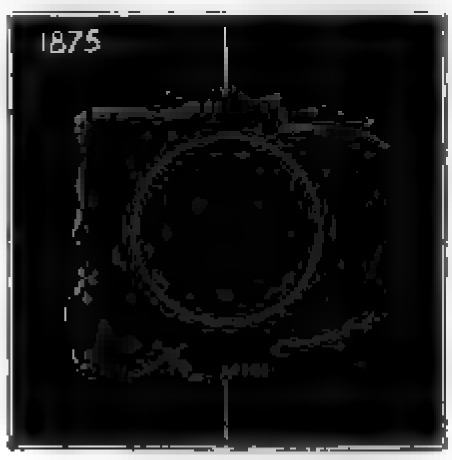
Lord Lindsay's and Col. Tennant's excellent series of negatives show a corona remarkably symmetrical, about a line inclined about 10° to the north-west and south-east of the Sun's axis. The northern and southern polar rifts are well defined, nearly opposite to one another, and very similar in character. The four synclinal groups are well marked, appearing to indicate zones of synclinal structure extending nearly from the pole to about 40° north and south latitude. These groups are generally separated from the equatorial portions by narrow definite rifts. The western margin of the south-east synclinal group shows a distinct tendency to double curvature—a form which reappears in 1883 and 1885. The extension is greatest in the equatorial regions, giving a somewhat hexagonal form to the corona. The great polar rifts are filled with short straight rays.

The greatest extent of the photographic corona does not exceed 27′, but the minuteness of the detail near the limb, which

with a strong transmitted light can be seen through the densest part of film, has never been equalled in any subsequent eclipse photograph. The remarkable feature of the lower structure is the prevalence of rays completely curving over, and of branching rays, somewhat resembling a frequent form of solar prominence. Few of these reach a height of more than 5′ from the limb; above this height the rays are generally straight or more slightly curved.

It is impossible to be certain whether these lower details are really near the limb, or whether they are rays on the nearer or further parts of the corona, seen foreshortened. In the latter case, they could hardly be the extreme ends of coronal rays, as these invariably fade away so much towards their extremities that they would certainly be lost on the dense background. On the whole, the difference of character between the higher and the lower details lends great probability to the view that the latter are really near the limb. Mr. Ranyard considers that the more contorted character of these lower structures indicates the existence of a resisting atmosphere in the lower part of the corona. It seems evident, at least, that many of the curvatures of the coronal rays could not be caused by gravity alone. Still when we consider what an intricate mass of crossing and interlacing rays must be produced by perspective as we approach the limb, we must feel that the question cannot be decided with certainty.

The eclipse occurred at a time of somewhat less solar activity than that of the previous year, Wolf's relative monthly number being 98.0.




*Eclipse of* 1875, *April* 6.

The small size of the photographs taken by Dr. Schuster renders it impossible to make out more than the general character of the corona, and from the same cause the orientation is not very accurately determined. The corona is somewhat symmetrical about a line nearly coinciding with the Sun's axis, the northern and southern polar rifts being very broad and well marked. Four synclinal groups are plainly seen, their axes making angles of more than 45° with the Sun's axis. The polar rifts are filled up, but not to a great height, the polar extension of the corona being only about half the equatorial, where

the greatest height is nearly a solar diameter. The half of the corona lying to the east of the axis is decidedly larger than that to the west, so that the nearly straight lines which bound the corona north and south converge towards the west. Dr. Schuster draws attention to the remarkable similarity between this corona and that of 1874, of which no photographs were taken. He thinks this similarity extends to the irregularity in the symmetry just mentioned; but the want of accordance between the drawings made in 1874 renders this uncertain.

Notwithstanding this general resemblance, the solar activity, as indicated by the sunspots, was less than half as great as in the previous year, Wolf's relative number for April 1874 being 49·1, and for April 1875, 20·5.


*Eclipse of 1878, July 29.*

The photographs which I have examined are two negatives by Mr. Ranyard, made at Denver, and a series of 9 positive copies on glass of the photographs taken by Professor Harkness and Mr. Rogers at Creston and La Junta. The exposures of Mr. Ranyard's plates were so short that they show but a small extent of corona. A drawing combining the detail of the Creston and La Junta negatives, and showing a further extension of the equatorial rays, from a smaller photograph by Mr. Peers, is given in the "Appendix to the Washington Observations" for 1876. On comparing this drawing with the positives, it does not seem very satisfactory. I can make out as much or more detail on the positives as on the drawing (except the equatorial extension), and no doubt much more would be seen on the original negatives.

The corona belongs to the same type as those of 1874 and 1875. The equatorial extension greatly exceeds the polar, and both the northern and southern rifts are widely opened, so that their eastern and western boundaries form nearly straight lines tangential to the limb The northern and southern synclinal groups are so much depressed towards the equator that they appear to coalesce into one great mass, occupying the whole equatorial region. The rifts are filled with fine rays, straight, and nearly radial in the centre of the rift, and becoming more and more curved towards its boundaries. In one rift there are as many as 20 separate rays, remarkably uniform in length and

distance apart, never branching or crossing. The two rifts are almost identical in character, but are not opposite each other; the northern rift having its general axis inclined about 15° towards the east from the Sun's axis, and the southern being more symmetrical with it.

The great equatorial extensions, of which the bases only are visible in the positives, are very symmetrical in detail, but the western mass is the broader, reaching further both to the north and south. These great masses are broadest near the limb, and gradually become narrower, so that their northern and southern boundaries would meet in a point about 2 diameters from the limb on the western side, and rather less on the eastern. These equatorial extensions were, however, observed by Newcomb, Langley, and others, to reach to a distance of at least 12 diameters. They must have been very faint, as in the American drawing, combined from various negatives, they do not extend more than a diameter.

It is a remarkable peculiarity, which I have observed in no other corona, that while at the poles it is split up into a great number of fine rays, the equatorial extensions are broad smooth masses, showing scarcely any detail, even at their extreme edges.

The eclipse occurred at a time of decidedly low solar activity, Wolf's relative number being only 3·3.


*Eclipse of* 1882, *May* 17.

The negatives taken by Dr. Schuster show a large extent of corona, reaching in several places a height of a solar diameter, one straight ray in the south-west extending as far as 1½ diameter. The corona presents none of the features which characterised those of 1874, 1875, and 1878. Although very irregular in detail, it is approximately circular in form, and is entirely without that great difference between the polar and equatorial extensions which had been so striking in the three

last eclipses. At the same time it shows none of that symmetry about a line not very far from the Sun's axis that had been more or less apparent in most previously photographed coronas, and especially in that of 1871. This absence of an axis of symmetry and of polar rifts is its most striking feature. There are groups of synclinal structure, but they are not of a very definite character, and are quite irregularly placed. The solar axis does not pass through the line of least extension, as is almost always the case. The only approach to an axis of symmetry seems to be about a line nearly at right angles with the Sun's axis. The orientation was, however, very carefully made, and in Dr. Schuster's opinion is not more than half a degree in error: it nearly agrees with that adopted by Professor Tacchini.

The rays are rather more frequently straight than curved, and there is only one instance of a ray completely curving over: this is in the south-east; it reaches a height of about 12′ from the limb. Beneath it are two rays—the only ones showing any traces of a branching structure. There are distinct rifts on the western side, reaching to the limb; but they are more filled up with coronal matter than those of 1871. The rays are in all directions, from radial to tangential, and there are several cases of rays crossing each other, but no clear case of a ray of double curvature. The lower details of the corona are less distinct than in 1871; but this may be due to the great density of the film near the limb, which is common to all dry-plate negatives. The definition of the outer portions is extremely fine. I cannot see any evidence of the distinction between an outer and inner corona, which Dr. Schuster thinks the photographs show. Wolf's relative monthly number of sunspots is 64·5; a remarkable outburst had occurred during the preceding month, for which the number was 95·8.

*Eclipse of* 1883, *May* 6.

Successful photographs were taken by M. Janssen, and also by Messrs. Lawrance and Woods. The most prominent feature is an unusually well-marked rift, partly filled with short straight rays, near the north pole of the Sun's axis, from which the general axis of the rift is inclined at an angle of about 30° to the east. On each side of this rift are most characteristic groups of synclinal structure, whose bases meet at the limb: the easternmost shows a double curvature on both sides, but on the western edge this appearance seems caused by the superposition of different rays. There seems no regularity in the arrangement of the rays in the rest of the corona, nor any rift in the south, corresponding to that in the north. The general outline of the corona is somewhat circular, but the two synclinal groups extend farther than any other part. In M. Janssen's long-exposed plate, one of these groups extends nearly as far as two solar diameters, which is the greatest extension shown by any corona photograph. Indeed, M. Janssen says that it is much greater than it appeared to the eye in his telescope.

The solar activity was rapidly decreasing, Wolf's relative monthly number of sunspots being 32·1.


*Eclipse of* 1885, *September* 8.

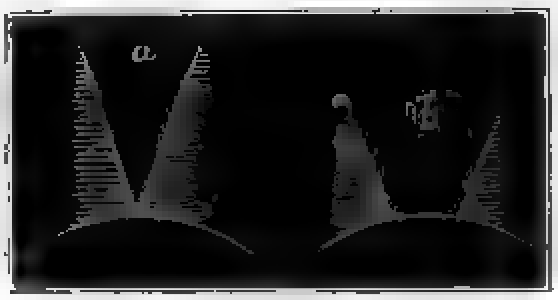
Several photographs were taken of this eclipse, but the weather was generally unfavourable, and few show much detail. The most marked feature is the southern rift, which is broad and well marked, with clear indications of straight rays filling it. The only distinctly synclinal group is to the south-east; its axis makes an angle of about 45° with the Sun's axis, and its extension is greater than any other part of the corona. The western edge of this group presents a double curvature. The other parts of the corona are very irregular, and there does not appear to be any distinct rift on the north corresponding with the southern rift. There is a marked broad depression in the corona, about 35° to the east of the north point of the axis. This depression, and the southern rift, appear to divide the corona into two very unequal parts, the western one being much the greater.

The solar activity, as shown by the sunspots, was diminish-

ing; Wolf's relative monthly number being 83·7 for the month of June, and 39·6 for September.

The results of the observations of the eclipses of 1883 and 1886 are in course of publication by the Royal Society, and I have not their permission to describe the details of the corona of these years.

Since the corona entirely surrounds the Sun, and is not a mere fringe as it necessarily seems to the eye, its appearance is greatly modified by perspective. The groups of synclinal structure, when they occur somewhat symmetrically on opposite sides of the Sun, must evidently be regarded as zones of curving rays, the shorter and straighter rays filling the polar rifts, being probably the rays on the nearer or further parts of the synclinal zone seen foreshortened. A curved tangential ray, if curved or inclined in the line of sight, will appear straight and radial but shortened. On the other hand, foreshortening may greatly increase the apparent curvature of a ray. The true point on the Sun from which a ray springs is not seen unless it springs from the limb. The polar rifts must be greatly modified in appearance if they are inclined in the line of sight. It is obvious that a rift which would resemble *a* if actually on the limb would be more like *b* if its axis were directed towards or from the Earth.




The greater apparent density of the corona near the limb must, of course, be largely due to its greater thickness. It is only at the extreme outer limits of the corona that we can see the true character of its rays, as it is only there that they are unaffected by perspective or superposition.

A large proportion of the coronal rays are curved, the curves being of various kinds. It frequently occurs, at the edges of the synclinal groups, that a ray which appears to spring from the limb in a nearly radial direction is abruptly curved, and then straightened, so as to become almost tangential: this is a most characteristic form of coronal ray. Sometimes after it has attained a considerable height it is slightly curved in a contrary direction, as is well seen in 1871, 1883, and 1885.

Rays completely curving over and branching rays have been mentioned in the description of the corona of 1871, in which they are very numerous; but they are scarcely seen in any other eclipse. Possibly they occur as a rule only near the limb, which portion has never been so clearly shown as in the photographs of 1871.

Dr. Huggins suggests that the curved rays may be caused by matter blown upwards, rising with the smaller rotational velocity of the photosphere from which it started, and appearing to lag behind in its ascent.* But in this case we should expect the curves to be similar in direction and character in any part of the corona, while in fact there is no such regularity, which seems to show that the curvature cannot be the result of this cause alone.

The coronal rays are invariably brighter near the limb, and fade gradually away towards their extremities, where they are sometimes pointed and sometimes spreading. Sometimes they rise from a broad extended base, which character may be more frequent in reality, as the base would be hidden if the ray is not upon or near the limb.

The absolute brightness and extension of the corona during different eclipses cannot be ascertained from the photographs, as they have been taken with various instruments and exposures, and on plates of different degrees of sensitiveness. The earlier collodion photographs probably never showed half the visible corona, while the recent negatives taken on dry plates with long exposures may show more than is visible to the eye.

The coronal matter is very transparent, many rays crossing others which are seen through them.

Nothing that I have seen on the eclipse photographs seems to give the least countenance to any of the meteoric theories of the corona. Drawings such as that of Liais in 1858, representing the synclinal groups as symmetrical cones, would be readily interpreted as streams of meteors passing round the sun; and drawings like Gillman's in 1869, giving innumerable rays all truly radial, might indicate matter falling into the Sun. In the photographs, however, the cones are never symmetrical, and are shown to consist of many rays of various curvatures, while rays that are truly radial are quite exceptional. If the rays were meteor streams sweeping past the Sun we should expect to trace the same streams at opposite sides, while in fact there is no such exact correspondence, even in the most symmetrical corona of 1878.

The detailed structure of the corona seems quite conclusive evidence against Professor Hastings's theory that it is a diffraction phenomenon.

Whatever may be the true cause of the corona, it is impossible for one who has examined the photographs to resist the conclusion that in some way it proceeds from the Sun. The character of the curved rays—especially those which curve com-

* Bakerian Lecture, *Proc. Roy. Soc.*, vol. xxxix. p. 127.

pletely over—the invariably greater brightness of the corona as it approaches the limb, the broad base from which the rays sometimes spring, all seem capable of no other explanation.

Although many observers have spoken of movement of the coronal rays, and have recorded changes of form during totality, there is nothing in the photographs to show that changes of such magnitude as to be visible have taken place in so short a time. Photographs taken an hour apart in 1871 show no visible change, while the clearness of the details proves the appearance of movement to have been an illusion.

I am unable to see in the eclipse photographs any ground for the distinction often drawn between an "inner" and "outer" corona. The principal details can generally be traced down to the limb, and there does not seem any sudden falling-off of the light (except what is caused by occasional strongly curved or foreshortened rays), nor other indication of a want of continuity. It seems to be of the same character throughout. At the same time, it may be true that the lower structures are more frequently of a strongly curved or branching character.

There is no sign of any connection between the coronal rays and the solar prominences.

The only generalisation with regard to the form of the corona which has seemed well supported by the photographic evidence is that of Mr. Ranyard, that there is a connection between the general form of the corona and the solar activity as shown by the number of sunspots. The corona of a sunspot maximum has generally been somewhat symmetrical, with synclinal groups making angles of 45° or less with its general axis. The sunspot minimum coronas show polar rifts much more widely open, synclinal zones making larger angles with the axis, and being therefore more depressed toward the equatorial regions, in which there is usually greater extension. This generalisation is well borne out by the maximum coronas of 1870 and 1871 and the minimum coronas of 1867, 1874, 1875, and 1878. On the other hand, the eclipses of 1883, 1885, and 1886, do not strikingly confirm the theory. The eclipse of 1883, at a time of rapidly decreasing solar activity, shows all the characters of a sunspot maximum corona; the same in a somewhat less degree may be said of 1885 and 1886, at both of which times the solar activity was decreasing. Although the polar rifts were wide in 1886, there was no marked depression of the synclinal groups towards the equator, nor any great equatorial extension, although the relative number of sunspots for August 1886 was only 16·9. Striking, therefore, as the evidence in favour of the generalisation has been in many years, it still seems probable that the form of the corona is modified by other causes at present unknown to us.

It may be that the coronal axis (to use a convenient term) is always inclined at the same angle to the Sun's axis of rotation, and that the apparent changes in its inclination are caused by its being seen from different points of view. Before this question

can be answered, photographs must be taken at every total eclipse for many years to come. It will, above all, be necessary, however, that the utmost care be taken in the orientation of the plates, that there may not be the slightest doubt as to the position of the Sun's axis. Unfortunately, on several of the eclipse photographs there is great uncertainty on this most important point. It is preferable to take a series of photographs of the solar crescent (by stopping the clockwork in the usual way) both before and after totality, so as to guard against the danger of any slight shift of the instrument.

Sometimes a wire has been placed in the instrument for the purpose of orientation; but wherever this crosses the corona it interferes with the details, and is on that account a disadvantage. In 1886 two pointers were used, one on either side, beyond the limits of the corona; but there is a risk of these not being visible on the plates. If the plate perfectly fit the plate-holder there hardly seems any necessity for a wire.

To prevent mistakes in orientation the plan adopted by Mr. Davis in 1871 was an excellent one. Each of his plates had one corner cut off, corresponding with a small fixed block in one corner of the exposing frame, so that no doubt could afterwards arise as to the position of each plate when exposed.

In the reports of the observations it need hardly be said that the data from which the orientation is obtained should always be fully stated.

It is much to be wished that in future eclipses photographs could be taken which would show the lower details as clearly as the negatives of 1871; I am almost inclined to recommend collodion plates, such as were then employed. The excessive density of the corona near the limb in all the dry-plate negatives obscures the lower details, while the greater coarseness of the grain makes it impossible to use much magnifying power in their examination. At the same time, we ought not to forego the great advantage of the gelatine film in giving the full extension of the corona. It is to be hoped that by some improvement in the preparation of plates both these advantages may be combined.

In the meantime careful drawings would be of great utility if observers would, instead of vainly trying to give a general view of the entire corona, which is quite impossible in the short time at their disposal, restrict themselves to making as exact delineations as possible of the details in some portion only. The general appearance of the corona is admirably given in a good photograph; but this would be most usefully supplemented by detailed drawings of selected portions, especially of the structure near the limb, in which the photograph most frequently fails.

1887, *June* 9.

## *Physical Observations of Saturn in* 1887.
## By Thomas Gwyn Elger.

The following observations of the planet were made with an 8½-in. silver-on-glass reflector by Calver during the months of February, March, and April.

*12th February*, $9^h$ to $10^h$. Good definition; East wind. Planet beautifully defined with a power of 350. *Rings.*—A. No trace of any division; outer border slightly darker than the remainder. B. Inner edge very dark. Ring gradually increasing in brightness to about midway between the interior and exterior borders. Outer half uniformly bright. C. Both ansæ extremely dark, hardly distinguishable except where it crosses the ball; here it is sufficiently transparent to allow the latter to be seen through it. *Belts.*—The broad equatorial belt is orange-yellow in colour, and sharply defined on its northern edge by a darker band of varying width. Its southern limits are marked by a much fainter band, the intervening space exhibiting a mottled appearance—due to the presence of light spots and markings. About midway between the bluish-grey polar cap and the equatorial zone there is a faint belt, but this region is very indistinct. *Shadow of ball.*—The *f* side of the sharply-defined shadow on B appears to be concave up to Cassini's division, where there is a well-marked notch, apparently coincident with the latter. South of this, on ring A, the shadow follows the curvature of the ball, and seems to be somewhat narrower than any portion of the shadow on ring B. The south limb of the ball is slightly within the outer edge of A.

*16th February*, $8^h$ to $9^h$. Frosty; wind N.E. Definition variable—not so good as on the 12th. Powers used, 284, 350. *Rings.*—A. Is similar in colour to the polar cap—viz. greyish-blue. There is an evident though faint light line concentric with the ring about midway between the outer and inner edge, but rather nearer the former. It can be traced for some distance on both ansæ, but is more easily seen on the *p* side. B. The shading on this ring becomes gradually lighter from the inner edge to a point about ¼th the apparent width of the belt from the outer edge, where it suddenly ceases, the remainder of the ring being uniformly bright. C. Dark, but distinct on *p* side. *f* ansa nearly indistinguishable. *Belts* less favourably seen than on the 12th.

*21st February*, $9^h$ to $9^h$ $30^m$. Definition variable. Power used, 350. *Rings.*—A. No trace of any detail. B. The bright outer edge appears to be of the same tone, but slightly more brilliant than the central portion of the ball immediately north of the equatorial belt. C. Both ansæ very dusky—scarcely distinguishable, except here and there. *Belts.*—North border of equatorial belt sharply defined. Mottled surface evident. Polar and intermediate zone indistinct. *Shadow of ball.*—As on the 12th

*25th February*, $9^h$ to $9^h$ $30^m$. Definition on the whole favourable. Power used, 350. *Rings.*—A. No detail seen; inner edge, adjoining Cassini's division, on *p* ansa somewhat darker than the general surface. B. As on the 21st. C. *p* ansa very obscure, in places as dark as the space between the ball and the ring system. Nothing abnormal was noted in connection with the *f* ansa, though at times the *n f* part of the ring seemed to be lighter than the remainder. *Belts.*—All badly defined.

*26th February*, $8^h$ $30^m$ to $9^h$ $30^m$. Clear frosty night with good definition. Powers used, 284, 350. *Rings.*—A. No detail visible. B. Gradually increasing in brightness from the inner to the outer edge, which is bounded by a narrow zone of uniform brilliancy about equal in width to Cassini's division. C. With both eyepieces the *p* ansa exhibits on its inner border three or four large re-entering angles like the teeth of a saw, the intervening spaces being apparently as dark as that between the ball and the ring, and extending nearly to the outer edge of the ring. This appearance is confined to the western section of the ansa, there being nothing abnormal as regards the *s p* and *n p* portion of it. The *f* ansa is dark but traceable. *Belts.*—Details well seen.

*27th February*, $9^h$ to $9^h$ $30^m$. Definition variable. Powers used, 284, 350. *Rings.*—A. Light line visible for some distance on both ansæ, as on the 16th inst. Inner edge slightly darker than the rest of the surface. B. As on the previous evening. C. The indented edge of the *p* ansa cannot be made out, but the surface of the ring is unequally dark. At times of best definition two or three dark areas are noted upon it with both eyepieces.

*28th February*, $9^h$ to $9^h$ $30^m$. Sky hazy. Good definition, affording some exquisite glimpses of the planet. Power used, 350. *Rings.*—A. Light streak seen on both ansæ, as on the 16th and 27th. C. Very dusky, only isolated areas of the *p* ansa visible. *Belts.*—Equatorial belt covered with ill-defined detail, and bounded on the north by a wide band, much darker than any other portion of the ruddy zone. Faint belt on the northern hemisphere visible near the east and west limb. The greater portion of it is hidden by the ring C, to which it is about equal in tone.

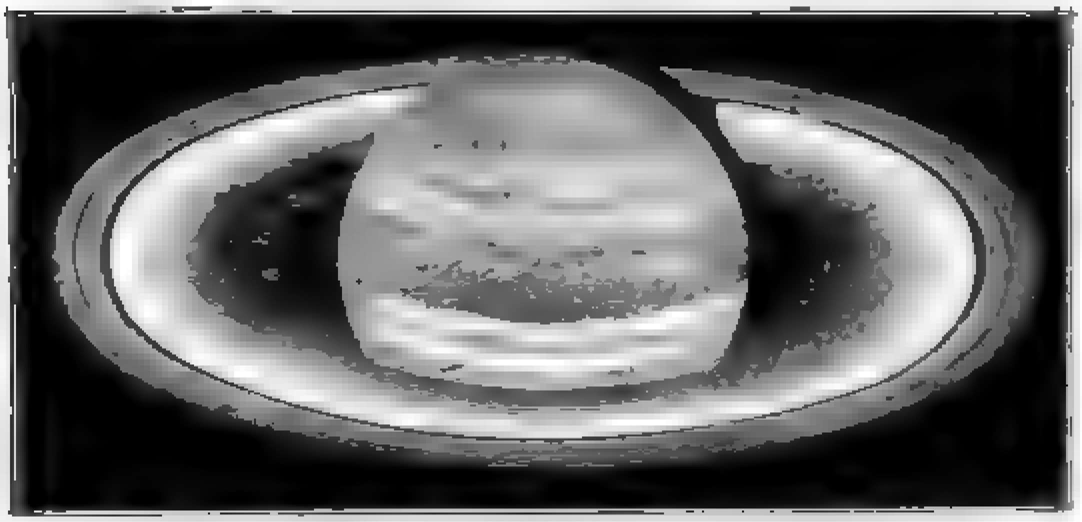
*12th March*, $8^h$ $30^m$ to $9^h$ $30^m$. Definition variable. Wind E. Powers used, 284, 350. *Rings.*—A. No detail visible. C. *p* ansa is very evidently broken up into several areas of different degrees of darkness, so that, except a short section of it, *n p*, it is impossible to recognise it as a ring surrounding the planet. The *f* ansa, on the contrary, is easily visible. *Belts.*—All fairly distinct. *Shadow of ball.*—The southern limb and outer edge of A are apparently coincident, and the shadow south of the well-marked notch at Cassini's division becomes gradually wider as it approaches the boundary of the ring.

13*th March*, $8^h$ $30^m$ to $9^h$ $15^m$. Frosty; E. wind. Definition variable. Powers used, 284, 350. *Rings.*—A. A faint dark line, presumably Encke's division, seen on the widest part of both ansæ. B. Inner edge very obscure, ring gradually increases in brilliancy to a point about $\frac{1}{3}$rd its apparent width from its outer edge, where it becomes suddenly bright. C. At times it is impossible to recognise any traces of this ring on the *p* side, though the *f* ansa is obvious enough. During the best definition, however, three or four large dusky areas are just distinguishable amid the general blackness of the space between the ball and the *p* ansa of B. *f* ansa very dark, but traceable. *Belts.*—Details well seen. *Shadow of ball.*—Extremely sharp; notch very evident; shadow falling on B slightly concave towards the east, becoming gradually wider from the notch to the outer edge of A.

16*th March*, $8^h$ $15^m$ to $9^h$ $15^m$. Frosty; E. wind. Definition variable, but at times excellent, affording superb views of the planet. Powers used, 284, 350. *Rings.*—A. When seen to the greatest perfection it seems to be of a lavender-grey hue, the *p* ansa being slightly darker and the *f* ansa much darker than the dusky northern edge of the equatorial belt. Encke's division is seen on the *p* side only; here it is an easy object, and can be followed for some distance round the ansa. During the most favourable glimpses both ansæ appear to be striated with faint concentric markings. B. The brilliant outer edge of this ring causes it apparently to stand up like a step in front of Cassini's division. The graduated shading is not so evident to-night. It seems to occupy about $\frac{2}{3}$rds of the width of the ring. C. The anomalous appearance of the *p* ansa again observed with both eyepieces. *f* ansa dark, but easily seen. *Belts.*—Equatorial zone covered with minute white spots on an orange-yellow background, and exhibiting much ill-defined detail. Its northern boundary consists of a dark band of irregular width, with a sharply-defined edge towards the north. The southern limit of the zone is marked by a similar but much fainter band. Polar cap, bluish-grey. A suspicion of two or three finer belts between this and the equatorial zone. About midway between the latter and the most northerly belt (which is partially hidden by C) there is a faint band, which at $9^h$ extended from the eastern limb across nearly three-fourths of the visible disc. That portion of the ball between the equatorial zone and C is much brighter and more decidedly yellow than the brightest part of the ring-system, viz. the outer portion of B.

18*th March*, $8^h$ to $9^h$. Wind E. Definition excellent. Powers used, 284, 350. *Rings.*—A. Encke's division steadily seen on both ansæ, and occasionally glimpsed all round the ring, though it is more distinct on the *p* ansa than elsewhere; here it is bordered on the inner side by a faint narrow light edge. B. As on March 16th. C. The anomalous condition of the *p* ansa very evident with both eyepieces; as on February 26th, it

exhibits a deeply jagged or indented edge, while there is a wide black space on the *s p* side concentric with B and adjoining it.* *f* ansa very obscure, but visible. *Belts.*—All the detail seen on the 16th inst. observed to great perfection. Faint band north of equatorial zone again visible, but it could only be clearly traced from the east limb to the centre.



*Saturn*, 18 March, 1887, $8^h$ to $9^h$. Thos. Gwyn Elger.

*24th March*, $9^h$ to $10^h$. Definition not good. Power used, 350. *Rings.*—A. No detail visible. C. Irregular outline of inner border in *p* ansa traceable, but ring very dark and indistinct. *f* ansa apparently normal, but very obscure.

*7th April*, $9^h$ to $9^h\ 30^m$. Definition variable—very good at times. Powers used, 284, 350. *Rings.*—A. No detail visible. C. The unsymmetrical inner border of the *p* ansa very conspicuous and remarkable as exhibiting a scalloped edge. The boundary between this ansa and B very ill-defined—so much so that it is difficult, as regards the *s p* portion, to trace any definite line of demarcation. *f* ansa very dark, hardly distinguishable from the space between ball and ring. *Belts.*—All well seen. Faint belt north of equatorial zone glimpsed once or twice on the *f* side of the centre. *Shadow of ball.*—Notch at Cassini's division seems decidedly blunter than it did a fortnight ago. The outer border of the shadow on A now runs up to the extreme point of the notch. The outline of the shadow both on A and B is evidently concave towards the east.

*10th April*, $8^h\ 20^m$ to $9^h\ 10^m$. Wind E. Definition variable, but at times excellent. Powers used, 284, 350, and 420. *Rings.*—A. No detail seen. B. As on 16th March. C. Irregular inner border of *p* ansa evident with all the eyepieces used, and a dark interval between C and B extending for some distance on either side the apparent major axis of the ring. Three or four dusky spots noticed on the surface of *f* ansa. These features satisfactorily seen with all powers. *Belts.*—Details finely seen,

* See accompanying drawing.

but no trace of delicate belt north of equatorial zone, observed on March 16th and 18th and on 7th April. *Shadow of ball.*—As the notch now projects very little beyond the outline of the shadow, it is very difficult to make out.

*11th April*, $8^h\ 30^m$ to $8^h\ 55^m$. Definition variable. Fine clear night; wind E. Powers used, 284, 350. *Rings.*—A. No detail seen. C. Irregular border glimpsed several times on *p* ansa. *f* ansa very obscure.

*14th April*, $8^h\ 30^m$ to $9^h\ 0^m$. Definition excellent. Wind N.E. Powers used, 284, 350, 420. *Rings.*—A. Encke's division steadily seen on both ansæ. B. As on 16th March. C. With all the eyepieces the inner edge of the *p* ansa is clearly serrated. Dark spots again visible on *f* ansa. *Belts.*—Beautifully distinct; faint belt north of equatorial zone, first seen on 16th March, traced from limb to limb.

*20th April*, $8^h\ 20^m$ to $9^h\ 0^m$. Definition pretty good. Powers used, 284, 350. *Rings.*—A. No detail visible. C. Both ansæ very dark. Irregular border of *p* ansa evident. The surface of ring in *f* ansa is manifestly irregular in tone, though no definite spots can be distinguished.—*Belts* not favourably seen. *Shadow of ball.*—It requires some attention to see the notch this evening; even at times of best definition there is hardly a recognisable projection at the Cassini division.

After this date, though several observations were attempted, the increasing duration of twilight and unfavourable weather prevented the details of the planet from being seen to advantage.

*Kempston, Beds:*
1887, *June* 6.

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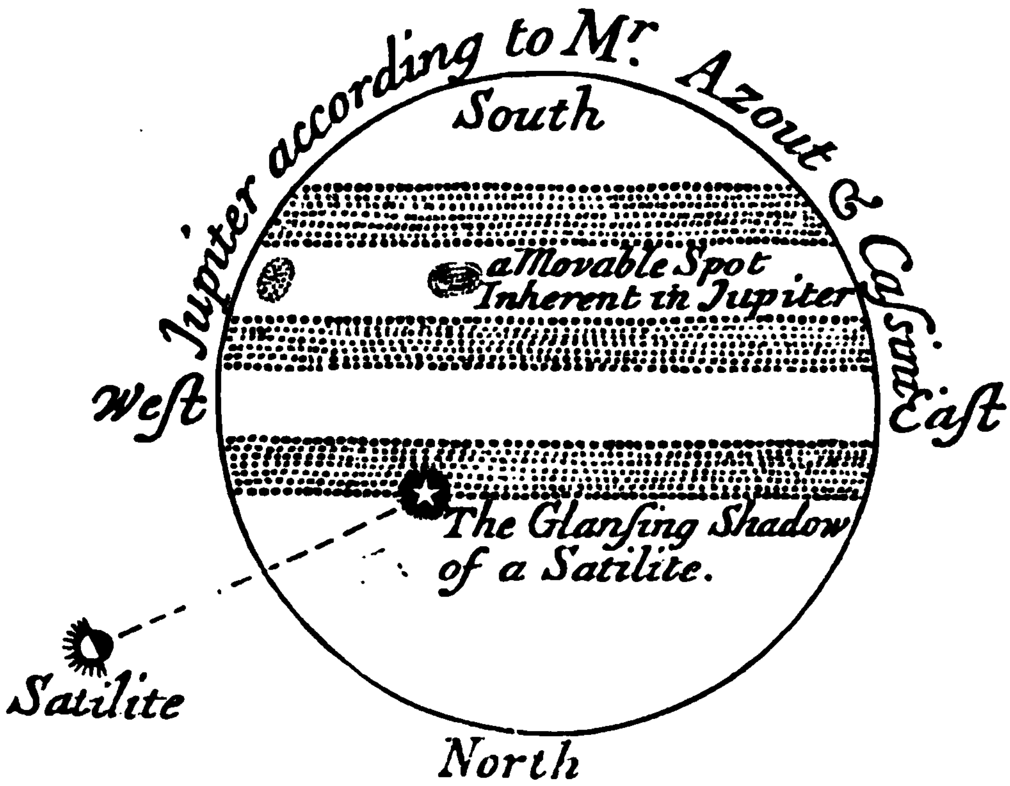
## *On an old Engraving of Jupiter.* By Captain W. Noble.

The other day, in the valuable library of old astronomical works belonging to my friend Mr. C. Leeson Prince, F.R.A.S., I came across a curious little volume, described on its title-page as "Atlas Cœlestis, containing the Systems and Theoryes of the Planets, the Constellations of the Starrs. Sold by Ben Bragg in Paternoster Row." Neither the author's name nor the date of publication is appended; but the name of "John Seller" appears in the corner of one of the plates, and, from a note in the body of the work with reference to an eclipse, it must have been published in 1680. Presumably this is the same John Seller who was the author of a quarto treatise on navigation which appears in the catalogue of our own library, and who produced a variety of books on arithmetic, astronomy, and navigation between the years 1671 and 1711. My immediate object, however, is to invite attention to one of Mr. Seller's engravings, which, through the kindness of Mr. Prince, I am able to reproduce in fac-simile.

The interest which I conceive to attach to this resides in the fact that the "movable spot inherent in *Jupiter*" shown in this old engraving is situated in precisely the same part of the planet's disc as the familiar red spot which has been watched of late years by so many scores—not to say hundreds—of observers. I have no means of access to Auzout's observations; but the early volumes of the *Philosophical Transactions* contain several notices of those of Cassini; and I have little doubt that one in the first volume (January 8, 1666), p. 143—"Of a permanent spot in *Jupiter*, by which is manifested the conversion of *Jupiter* about his own axis"—has reference to the very marking which Sellers draws. The words are these: "Besides that transient shadow" (of a satellite) "last mentioned * there hath been observed by Mons. Cassini a permanent spot in the disque of




*Jupiter*; by the help whereof he hath been able to observe not onely that *Jupiter* turns about upon his own axis, but also the time of such conversion, which he estimates to be $9^h$ $56^m$." Again, on p. 172 of the same volume (February 1666), after speaking of changes in "the three obscure belts" of *Jupiter* detected by Cassini, the account goes on to say that he (Cassini) "hath at length discovered a permanent spot in the northern part of the most southern belt, by the means whereof he hath concluded that *Jupiter* turns about his axis in 9 dayes" (an obvious *lapsus* for hours) "56 minutes." This is followed by a somewhat elaborate argument to show that the spot is actually attached to the surface of the planet, from the different manner in which it and the shadow of a satellite behave in traversing *Jupiter's* disc; and then the account goes on to say that Cassini "hath calculated many tables whereof he gives the explication and use in the letters by him addressed to the Abbot Falconière. By the means of them one may know when this spot may be seen by us . . . and shews by his tables what is to be added or

* This is, I suspect, the "Glansing Shadow of a Satilite" of the engraving.—W. N.

substracted to know at what time the said spot is to come into the middle of *Jupiter's* diske." In all of which Cassini only anticipated Mr. Marth by two hundred years or so. In connection with this it is noteworthy that in the year 1858 a remarkable dark spot appeared upon the face of *Jupiter*, in the same part of his disc. My first intention was to have copied a drawing of my own, made at this date, to illustrate this, but I find one by Mr. Lassell on p. 52 of vol. xix. of the *Monthly Notices*, in which the spot is depicted. Putting all this together, it would appear that a permanent source of disturbance exists in a very circumscribed region to the south of *Jupiter's* equator, and that in observing the red spot we are probably only watching the marking by which the first determination of *Jupiter's* period of rotation was ever made.

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## *On Prof. G. W. Hill's Paper on Delaunay's Method.*
By Edmund Neison.

It had been my intention to have passed over in silence Prof. Hill's paper in the November number of the *Monthly Notices*, entitled, "A Reply to Mr. Neison's Strictures on Delaunay's Method of Determining the Planetary Perturbations of the Moon;" but it has been pointed out to me that, as the question involved is one which cannot readily be followed by most astronomers, it is proper that I should make known my dissent from the superficial criticisms urged by Prof. Hill, based as they are on so much misconception, betraying as they do such imperfect acquaintance with the previous history of the question, and supported as they are by no evidence beyond strong unsupported assertion. The whole paper is unjustifiable, unless we accept as incontrovertible the point of view from which the whole is written—namely that, because I differ from Delaunay, I must have a confused, erroneous conception of his method, and must be entirely in the wrong! The very key-note to the tone of the paper is given in almost the opening paragraph, that "If we were obliged to admit the validity of *all* the statements in this article, an easy corollary from them would be that Lagrange's general method of the variation of arbitrary constants in the problems of mechanics was a blunder. Now, I think that no one acquainted with this method could, for a moment even, entertain such a proposition. Hence, we may conclude there is some flaw in the reasoning of this paper." As a simple assertion this is strong enough and, polemically, may be good, but if Prof. Hill undertakes to substantiate his assertion it will be *he* who will have made the blunder.

I do not wish even to seem wanting in courtesy to Prof. Hill, whose valuable contributions to the Lunar Theory have always commanded my warmest admiration; but I cannot admit that the objections raised by him in this paper are such as to call for any serious reply.

Perhaps there are two points which might be noticed.

1. Prof. Hill's justification of Delaunay is singularly enough the simple reiteration of the unquestionable error dealt with in my very paper, where I clearly showed that it was no justification of Delaunay to say that he neglected these quantities depending on $m^4$, $m^5$, $m^6$, $m^7$ . . . ., because they were beyond the order of approximation fixed by him, and seemed obviously to be very small, because in the face of Hansen's explicit statement that, according to his calculations, it was these terms and these only which yielded the large values found by him, Delaunay was bound to so fix the order of his approximations that these terms were included. For remember that Delaunay was verifying Hansen's results; he was bound to include all included by Hansen, and in interpreting Hansen's statements was bound to assign Hansen's meaning to Hansen's words; so it is useless to try to evade the difficulty, as Prof. Hill does on p. 2, by assigning to Hansen's words a new and forced meaning that was never employed by Hansen or any of his contemporaries.

2. Prof. Hill points out how amusing it would be if it should "turn out that the set of values withheld from publication by Hansen were identical with those of Delaunay." Amusing! Very! in the face of Hansen's letter to Leverrier shortly before his death, in which he again expresses his complete disagreement with Delaunay's results, and his conviction from his calculations that, despite Delaunay, both the terms in question had sensible coefficients.

The question at issue may be stated thus:

By the ordinary direct methods of dealing with this problem, methods whose soundness, simplicity, and adequacy is unquestionable, there are obtained in the value of these coefficients certain quantities of the order $m^6$, $m^7$ . . . . depending on the higher powers of the disturbing force, which give rise to sensible values to these terms of long period. By the use of Delaunay's complex method neither he nor his followers have been able to obtain these terms. They argue—We do not obtain them, therefore they cannot exist. Hence, you ought not to get them by the ordinary direct methods, consequently those you do get must really disappear in some unexplained manner. The reply is—No; the onus of proving this disappearance lies with you; if you cannot derive them from your special method, the presumption is that you are not properly using your special method, so it is yielding you imperfect results.

Having now explicitly expressed my dissent from Prof. Hill's criticisms, I shall defer all further remarks to my Memoir on this subject, when I will show still more explicitly than I have yet done how Delaunay's application of his method to the computation of these terms is vitiated by an implicit assumption analogous in principle to that which would be made by assuming

$$f(\mathrm{R}\,.\,\mathrm{R}'+\mathrm{R}'')=f(\mathrm{R}\,.\,\mathrm{R}')+f(\mathrm{R}\,.\,\mathrm{R}'').$$

*Natal Observatory:*
1887, *April* 11.

## *Note on the Performance of the Westminster Clock.*
## By Thomas Buckney:

The reputation of the great clock of the Houses of Parliament is so well established that some adequate reason must be given to justify any further reference to its performance here. This will, I think, be furnished by an inspection of its error from Greenwich time on each day of the period under review, viz., from March 29 last until June 9. The clock, as is well understood, is not allowed to run for an indefinite time with an accumulated error like an astronomical clock, but is kept as close to Greenwich time as possible, the necessary correction being made as soon as the error reaches 2 seconds either fast or slow. The pendulum is never stopped for this purpose, but alterations of rate are effected by the addition or removal of small weights in such a way as practically to shorten or lengthen the pendulum, whilst errors of 4 seconds or more are corrected by stopping the train of wheels or allowing them to run on for a few seconds as may be necessary. Four seconds is, however, the smallest alteration that can be made in this way. Now the clock, which, in common with most others in the country, was stopped by the snowstorm of Dec. 26 last (the snow having blocked the path of the hands), had since been going very well, requiring, however, small corrections from time to time. The last of these was made on March 29, and since that day no alteration or correction whatever has been made.

The following table shows the daily error of the clock since that time, and the figures, which have been kindly furnished by the Astronomer Royal from the records of the Royal Observatory, may be taken as authentic. It should be mentioned that the clock automatically reports itself by electric current to the Royal Observatory twice daily:

| 1887. | secs. | 1887. | secs. | 1887. | secs. | 1887. | secs. |
|---|---|---|---|---|---|---|---|
| March 29 | −0·0 | April 9 | −2·0 | April 20 | −1·0 | May 1 | −1·0 |
| 30 | −0·0 | 10 | −* | 21 | −2·0 | 2 | −2·0 |
| 31 | −1·0 | 11 | −1·0 | 22 | −2·0 | 3 | −1·0 |
| April 1 | −1·0 | 12 | −1·0 | 23 | −1·0 | 4 | −1·0 |
| 2 | −1·0 | 13 | −1·0 | 24 | −1·5 | 5 | −1·0 |
| 3 | −3·0 | 14 | −1·0 | 25 | −2·0 | 6 | −1·0 |
| 4 | −2·0 | 15 | −1·0 | 26 | −1·0 | 7 | −1·0 |
| 5 | −2·0 | 16 | −1·0 | 27 | −1·5 | 8 | −1·0 |
| 6 | −2·0 | 17 | −1·0 | 28 | −2·0 | 9 | −1·0 |
| 7 | −2·0 | 18 | −1·0 | 29 | −1·5 | 10 | −1·0 |
| 8 | −* | 19 | −1·0 | 30 | −1·5 | 11 | −2·0 |

* No observation taken on these days.

| 1887. | secs. | 1887. | secs. | 1887. | secs. | 1887. | secs. |
|---|---|---|---|---|---|---|---|
| May 12 | −2·0 | May 20 | −2·0 | May 27 | −2·0 | June 3 | −1·0 |
| 13 | −2·0 | 21 | −2·0 | 28 | −2·0 | 4 | −1·0 |
| 14 | −2·0 | 22 | −2·0 | 29 | −1·0 | 5 | −0·0 |
| 15 | −2·0 | 23 | −2·0 | 30 | −1·0 | 6 | −0·0 |
| 16 | −2·0 | 24 | −2·0 | 31 | −2·0 | 7 | −0·0 |
| 17 | −2·0 | 25 | −2·0 | June 1 | −1·0 | 8 | +1·0 |
| 18 | −2·0 | 26 | −* | 2 | −1·0 | 9 | +0·7 |
| 19 | −2·0 | | | | | | |

An inspection of these figures will show that on March 29 the clock was exactly to Greenwich time, and again on June 5, 6, and 7. In the meantime it had made small variations, its greatest error having been 3 seconds on April 3. The most remarkable part of the table is the period comprised between May 11 and May 28, the clock having maintained an error of 2 seconds without any variation whatever, and on 30 out of the 72 days its error was exactly 1 second—but these were not consecutive days—one group, however, of 10 days in succession being noted.

I believe this performance is unprecedented, so it may deserve to be placed on record.

1887, *June* 9.

P.S.—The clock is still 2 secs. slow, no correction having been required up to the present time, July 6th.

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## *Note on the Orbit of Comet Ross* (1883 *II.*) By Lieut.-General J. F. Tennant, R.E., F.R.S.

Mr. Bryant has pointed out two errors in the "Comparisons of the Observations of Mr. Ross's Comet (II. of 1883)" with my ephemeris, which would considerably affect the last normal place, and which, moreover, render the observations so much more accordant that it would now be worth while to get normals with more trouble. The gross result would possibly be to approximate to his orbit, and I hasten to recognise the defect of that I proposed.

* No observation taken on this day.

Vol. XLVII. Supplementary Number. No. 9

# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY.

## *The Sidereal System, Revised in* 1887. By Maxwell Hall.

Ten years have now elapsed since my article on "The Sidereal System" appeared in vol. xliii. of the *Memoirs of the Royal Astronomical Society*, and during this time much work has been done in sidereal astronomy: the annual parallaxes of several more stars have been ascertained by different observers and computers; the velocities of stars along the line of sight have formed a special branch of investigation at the Royal Observatory, Greenwich; Dr. Gill, at the Royal Observatory, Cape of Good Hope, has found that the parallax of about $0''\cdot936$ ascribed to the star *α Centauri** by his predecessors Henderson and Maclear is a little too large, and has thereby confirmed the researches of Dr. Elkin; and, lastly, the Greenwich observations show that the radial velocity of *Sirius* is variable,† and the curve of variation indicates that any constant part will prove to be small, so that theory and observation agree in the case of this important star.

These considerations render a revision of that article highly advisable; and we feel encouraged to take a somewhat wider view of the system than was possible in our first attempt; for we had then but few stars to deal with, and the general assump-

* One of the three stars employed in the former determination of the constants of the system.

† Reference was made in the first article to an assumed variation in consequence of the orbital motion of *Sirius* as a binary star, and the connection requires special investigation. A note will be found at the end of this article respecting the curve of variation.

tion of circular motion round the centre was absolutely necessary; but now we may discriminate, and say that among the elliptic orbits of the stars there must be several nearly circular, so that by assuming them to be truly circular the constants of the system may be accordingly determined.

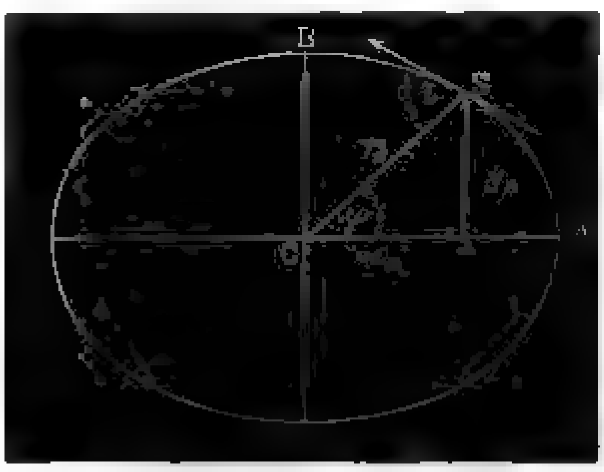
This wider and doubtless more correct view of the sidereal system requires but little change among our former equations; by means of proper motions we must compute parallaxes and radial velocities as before; and if in the case of any star the difference between observation and computation be large, or if the computation breaks down by assigning a negative parallax, the orbit cannot be circular and the star cannot assist us in the determination of the constants of the system.

But before dismissing such a star we may first ascertain whether its orbit be slightly or highly elliptic, for while we are prepared to admit into the sidereal system a large proportion of moderately elliptic orbits, a preponderance of highly elliptic orbits would throw great doubt upon our investigations.

There will, therefore, be three classes of orbits: those which are either circular or nearly so, those which are moderately elliptic, and those which are highly elliptic.

Stars which move in the last class of orbits will generally have large proper motions; and that such stars should have been selected for observation of annual parallax may be regarded as unfortunate for our problem, for we have thus forced upon us, as it were, an undue proportion of stars whose abnormal velocities and orbits must always distract our attention.

Let us now consider the motion of a star in the plane of its elliptic orbit about the centre, C.




Let $a_0'$ and $b_0'$ * be the semi-major and semi-minor axes C A and C B; and taking these rectangular axes as the axes of Cartesian co-ordinates, we have:

* The unit of space in quantities marked with these suffixes is the distance of a star whose parallax is 1″; in all other quantities the unit is the mean distance of the Earth from the Sun.

$$\frac{d^2x}{dt^2} = -Fx_0,$$

$$\frac{d^2y}{dt^2} = -Fy_0;$$

$$\left(\frac{dx}{dt}\right)^2 = F(a_0'^2 - x_0^2)$$

$$\left(\frac{dy}{dt}\right)^2 = F(b_0'^2 - y_0^2);$$

and

$$v^2 = F(a_0'^2 + b_0'^2 - r_0^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (V)$$

where F, $v$, and $r_0$ have the same significance as in the original article.

Again, let $\psi$ be the angle ACS, or the eccentric anomaly; then

$$x_0 = a_0' \cos\psi; \quad y_0 = b_0' \sin\psi;$$

$$\frac{dx}{dt} = -\sqrt{F} \,.\, a_0' \sin\psi; \quad \frac{dy}{dt} = \sqrt{F} \,.\, b_0' \cos\psi;$$

so that if $h$ be twice the area swept over by the radius vector in the unit of time,

$$h = x\frac{dy}{dt} - y\frac{dx}{dt} = a'b' \sqrt{F} \,.\, \sin 1'',$$

and the period of revolution is

$$\frac{2\pi}{\sqrt{F} \,.\, \sin 1''}.$$

Now let $i$ be the angle between the radius SC and the direction of motion of the star; then

$$v \cos i = \frac{dr}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (VI)$$

and

$$h = vr \sin i,$$

so that

$$vr_0 \sin i = a_0' b_0' \sqrt{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (VII)$$

Equation (V) can be rendered more convenient for our present purposes. Let

$$a_0'^2 + b_0'^2 = 2r_0^2 + \frac{\Lambda}{F}v^2;$$

then

$$v^2 = Fr_0^2 + \Lambda v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and in the case of the solar orbit,

$$V^2 = FR_0^2 + \Lambda V^2.$$

But we shall still consider the solar orbit to be circular, as in the former article, although indeed we recognise the necessity of determining its ellipticity at some future time; therefore we shall put $\Lambda = o$.

Substituting for the equations (I) and (II) in the former article in (13), we have

$$\left(\frac{d\rho}{dt}\right)^2 + 2aV\frac{d\rho}{dt} + (c^2 - \Pi^2 V^2)\rho_0^2 + 2V(b - H\Pi V)\rho_0 = \Lambda v^2 \quad . \quad . \quad . \quad (14)$$

Again, for elliptic orbits, equation (III) in the former article becomes

$$\frac{d\rho}{dt}(H + \Pi\rho_0) + \rho_0(K + a\Pi V) + \Gamma V = \Pi r_0 \frac{dr}{dt};$$

and remembering that

$$\Gamma V = \frac{dR}{dt} = 0,$$

we have

$$\frac{d\rho}{dt}(H + \Pi\rho_0) + \rho_0(K + a\Pi V) = \Pi r_0 \frac{dr}{dt} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Now when both $\rho_0$ and $\frac{d\rho}{dt}$ are known, of course $\Lambda v^2$ becomes known from (14), and $\frac{dr}{dt}$ from (15). When only $\rho_0$ or $\frac{d\rho}{dt}$ is known, $\Lambda v^2$ is indeterminate; but in many cases we may assign to $\Lambda v^2$ its lowest value, so that the quadratic equation may have possible and equal roots, or so that the resulting value of $\frac{dr}{dt}$ from (15) may be fairly in accordance.

Thus no value of $\Lambda v^2$ can be assumed in (14) which would make cos $i$ in (VI) greater than unity; and no value of $\Lambda v^2$ should be assumed in (14) which would make cos $i$ unnecessarily large.

Again, when $\Lambda v^2$ and $\frac{dr}{dt}$ are known, or roughly approximated, the corresponding values of $r_0$, $v$, and $i$ become known; also $(a_0'^2 + b_0'^2)$ and $a_0'b_0'$; so that $a_0'$ and $b_0'$ are known; and finally we have the ellipticity of the orbit, which is

$$\frac{a_0' - b_0'}{a_0'}.$$

Let us take as an example the star 17,415 Oeltzen;* it was shown that when the proper motions of this star are employed in the general formulæ, p. 186 of the original article, the resulting parallax has a negative sign; consequently the orbit of this star cannot be circular.

The observed parallax is 0″·247; therefore $\rho_0$ is 4·05, and equation (14) becomes

$$\left(\frac{d\rho}{dt}\right)^2 + 16{\cdot}3\frac{d\rho}{dt} = \Lambda v^2 - 84{\cdot}7,$$

so that

$$\left(\frac{d\rho}{dt} + 8{\cdot}15\right)^2 = \Lambda v^2 - 18{\cdot}3.$$

* No. 67 in the following tables.

Consequently the least possible value of $Av^2$ is $+18{\cdot}3$; and then $\frac{d\rho}{dt}$ becomes $-8{\cdot}15$.

Substituting these values of $\rho_0$ and $\frac{d\rho}{dt}$ in equation (15), we get

$$\Pi r_0 \frac{dr}{dt} = +5{\cdot}9.$$

But $r_0 = 149$ from (I); so that

$$\Pi r_0 = 0{\cdot}99,$$

and

$$\frac{dr}{dt} = +6{\cdot}0.$$

Again, from (II) or (13), $v = 10{\cdot}7$; so that from (VI), $\cos i = 0{\cdot}56$; consequently while $Av^2$ indicates a very small ellipticity, $\cos i$ indicates a much larger one.

Let us therefore assume

$$Av^2 = +118{\cdot}3;$$

then

$$\frac{d\rho}{dt} = +1{\cdot}85, \quad \frac{dr}{dt} = +2{\cdot}7, \quad v = 14{\cdot}7,$$

and

$$\cos i = 0{\cdot}18,$$

so that

$$i = 80^\circ.$$

Now, while we cannot say which of these two solutions is the more correct, we prefer the latter, and place the star 17·415 Oeltzen among those of the second class whose orbits are moderately elliptic.

Proceeding with the latter solution, $(a_0'^2 + b_0'^2) = 71461$, $a_0'b_0' = 32623$; $a_0' = 224$, $b_0' = 146$; and the ellipticity $= 0{\cdot}35$.

Let us take as another example the star 1830 Groombridge*; when the proper motions of this star are employed in the general formulæ, the resulting parallax becomes far too large, and therefore the orbit of this star cannot be circular.

The observed parallax may be taken as $0''{\cdot}145$; therefore $\rho_0$ is $6{\cdot}90$; and equation (14) becomes

$$\left(\frac{d\rho}{dt}\right)^2 + 8{\cdot}3\frac{d\rho}{dt} = Av^2 - 2476,$$

so that

$$\left(\frac{d\rho}{dt} + 4{\cdot}15\right)^2 = Av^2 - 2459.$$

Consequently the least possible value of $Av^2$ is $+2459$; and then

$$\frac{d\rho}{dt} = -4{\cdot}15.$$

* No. 62 in the following tables.

Substituting these values of $\rho_0$ and $\frac{d\rho}{dt}$ in equation (15) we get

$$\Pi r_0 \frac{dr}{dt} = +39.2,$$

so that

$$\frac{dr}{dt} = +39;$$

and as $v = 51$, $\cos i = 0.76$, and $i = 40°.5$.

The orbit of the star 1830 Groombridge is therefore highly elliptic; and proceeding numerically, $a_0' = 774$, $b_0' = 98$, and the ellipticity $= 0.87$.

Remembering that the radius of the solar orbit was found to be 150, it appears that the semi-major axis of this star is about five times as large; and in the solar system we are well acquainted with such relations between planetary and cometary orbits.

The following table requires but little explanation; the stars are arranged according to magnitude; the magnitudes given are for the most part the means of the results found by Professors Pritchard and Pickering; the Right Ascensions are given in time to the nearest second, but in the calculations they were previously expressed in arc to the nearest minute; the columns "P.M. in R.A." and "P.M. in N.P.D." give the proper motions in Right Ascension and North Polar Distance respectively, and the latter have been taken, when possible, from the papers of Professors Main and Stone in vols. xix., xxviii., and xxxiii., of the *Memoirs of the Royal Astronomical Society*; and a list of the proper motions taken from other authorities will be found at the end of this article, together with notes on the annual parallaxes and radial velocities which have been adopted.

It will be noticed that instead of merely indicating to which class the orbit of any star belongs, the adopted values of $\Lambda v^2$ and $\Pi r_0 \frac{dr}{dt}$ have been tabulated; when an orbit is assumed to be circular, these values are of course zero; when an orbit is assumed to be elliptic the values given are those which were roughly adopted as previously explained.

It will be convenient to reproduce the formulæ given in the first article,* p. 186, and to add those required for elliptic orbits.

*Formulæ.*

$\left.\begin{array}{l}\theta = \text{North Polar Distance} \\ \phi = \text{Right Ascension}\end{array}\right\}$ of a star, Jan. 1·0, 1850;

$\left.\begin{array}{l}\delta\theta = \text{Annual proper motion in } \theta \\ \delta\phi = \text{Annual proper motion in } \phi\end{array}\right\}$ in seconds of arc;

* A small list of *errata* in that article will be found in the *Monthly Notices*, vol. xxxix. p. 133.

$\varpi$ = Annual parallax, in seconds of arc;

$\rho_0$ = Distance in sidereal units $= \frac{1}{\varpi}$;

$\frac{d\rho}{dt}$ = Annual change in distance, taking the radius of the Earth's orbit as the unit of space.

$$\begin{aligned} l &= \sin\theta\cos\phi, & \delta l &= n\delta\theta\cos\phi - m\,\delta\phi, \\ m &= \sin\theta\sin\phi, & \delta m &= n\delta\theta\sin\phi + l\,\delta\phi, \\ n &= \cos\theta, & \delta n &= -\sin\theta\,\delta\theta. \end{aligned}$$

$$\begin{aligned} a &= l\lambda + m\mu + n\nu, & \log\lambda &= -9\cdot16642, \\ b &= \lambda\delta l + \mu\delta m + \nu\delta n, & \log\mu &= -9\cdot91350, \\ c^2 &= \delta l^2 + \delta m^2 + \delta n^2, & \log\nu &= +9\cdot74360. \end{aligned}$$

$$\begin{aligned} & & \log L &= -9\cdot94601, \\ H &= lL + mM + nN, & \log M &= -9\cdot15806, \\ K &= L\delta l + M\delta m + N\delta n, & \log N &= -9\cdot64992. \end{aligned}$$

*For Circular Orbits.*

$$u = \frac{K + a\Pi V}{H + \Pi\rho_0};$$

$$\begin{aligned} & & \log\Pi &= 7\cdot82282, \\ \varpi &= \frac{c^2 + u^2 - \Pi^2V^2}{2V(au - b + H\Pi V)}; & \log\Pi V &= 8\cdot82034, \\ & & \log 2V &= 11\cdot29855, \\ & & \Pi^2V^2 &= 0\cdot004. \end{aligned}$$

$$\frac{d\rho}{dt} = -\frac{u}{\varpi}.$$

*For Elliptic Orbits.*

$$\left(\frac{d\rho}{dt}\right)^2 + 2aV\frac{d\rho}{dt} + (c^2 - \Pi^2V^2)\rho_0^2 + 2V(bH\Pi V)\rho_0 = \Lambda v^2;$$

$$\frac{d\rho}{dt}(H + \Pi\rho_0) + \rho_0(K + a\Pi V) = \Pi r_0\frac{dr}{dt};$$

$$r_0^2 = R_0^2 + \rho_0^2 + 2HR_0\rho_0;$$

$$v^2 = V^2 + \left(\frac{d\rho}{dt}\right)^2 + 2V\left(a\frac{d\rho}{dt} + b\rho_0\right) + c^2\rho_0^2,$$

or more simply

$$v^2 = Fr_0^2 + \Lambda v^2;$$

$$\begin{aligned} & & \log 2R_0 &= 12\cdot47821, \\ v\cos i &= \frac{dr}{dt}. & \log F &= 7\cdot64068; \\ & & R_0^2 &= 22613, \\ & & V^2 &= 98\cdot9. \end{aligned}$$

| No. | Star | M | R.A. 1850 | P.M. in R.A. | N.P.D. 1850 | P.M. in N.P.D. |
|---|---|---|---|---|---|---|
| | | | h m s | s | ° ′ | ″ |
| 1 | α Canis Maj. (*Sirius*) | −1·2 | 6 38 32 | −0·035 | 106 31 | +1·24 |
| 2 | α Argûs (*Canopus*) | −0·4 | 6 20 37 | −0·002 | 142 37 | −0·03 |
| 3 | α Centauri | 0·0 | 14 29 27 | −0·484 | 150 13 | −0·75 |
| 4 | α Boötis (*Arcturus*) | 0·0 | 14 8 49 | −0·079 | 70 2 | +1·93 |
| 5 | α Aurigæ (*Capella*) | 0·1 | 5 5 37 | +0·008 | 44 10 | +0·43 |
| 6 | α Lyræ (*Vega*) | 0·2 | 18 31 51 | +0·017 | 51 21 | −0·28 |
| 7 | β Orionis (*Rigel*) | 0·2 | 5 7 20 | −0·001 | 98 23 | +0·02 |
| 8 | α Canis Min. (*Procyon*) | 0·5 | 7 31 27 | −0·048 | 84 24 | +1·08 |
| 9 | α Orionis | 0·9 | 5 47 3 | +0·001 | 82 38 | 0·00 |
| 10 | α Aquilæ (*Altair*) | 1·0 | 19 43 28 | +0·036 | 81 32 | −0·38 |
| 11 | β Centauri | 1·0 | 13 53 17 | −0·010 | 149 39 | +0·05 |
| 12 | α Tauri (*Aldebaran*) | 1·1 | 4 27 19 | +0·004 | 73 48 | +0·17 |
| 13 | α Virginis (*Spica*) | 1·1 | 13 17 18 | −0·005 | 100 23 | +0·04 |
| 14 | β Gemin. (*Pollux*) | 1·2 | 7 36 8 | −0·049 | 61 37 | +0·06 |
| 15 | α Leonis (*Regulus*) | 1·3 | 10 0 23 | −0·019 | 77 18 | −0·01 |
| 16 | α Cygni | 1·4 | 20 36 19 | −0·002 | 45 15 | 0·00 |
| 17 | α Gemin. (*Castor*) | 1·5 | 7 25 1 | −0·013 | 57 47 | +0·08 |
| 18 | ε Ursæ Majoris | 1·8 | 12 47 25 | +0·013 | 33 14 | +0·05 |
| 19 | α Persei | 1·9 | 3 13 38 | +0·002 | 40 41 | +0·05 |
| 20 | β Tauri | 1·9 | 5 16 49 | +0·003 | 61 31 | +0·20 |
| 21 | α Andromedæ | 2·1 | 0 0 39 | +0·009 | 61 44 | +0·15 |
| 22 | β Ceti | 2·1 | 0 36 3 | +0·013 | 108 49 | −0·02 |
| 23 | α Ursæ Min. (*Polaris*) | 2·1 | 1 5 1 | +0·065 | 1 29 | 0·00 |
| 24 | α Arietis | 2·1 | 1 58 44 | +0·012 | 67 15 | +0·15 |
| 25 | γ Cassiopeæ | 2·2 | 0 47 42 | −0·008 | 30 6 | −0·02 |
| 26 | γ Leonis | 2·2 | 10 11 42 | +0·019 | 69 24 | +0·15 |
| 27 | ζ Ursæ Majoris | 2·2 | 13 17 53 | +0·017 | 34 17 | +0·04 |
| 28 | α Ophiuchi | 2·2 | 17 27 58 | +0·004 | 77 20 | +0·20 |
| 29 | α Coronæ | 2·3 | 15 28 20 | +0·009 | 62 47 | +0·07 |
| 30 | γ Cygni | 2·3 | 20 16 51 | 0·000 | 50 13 | −0·02 |
| 31 | β Cassiopeæ | 2·4 | 0 1 12 | +0·063 | 31 41 | +0·19 |
| 32 | β Ursæ Majoris | 2·4 | 10 52 45 | +0·010 | 32 49 | −0·03 |
| 33 | γ Ursæ Majoris | 2·4 | 11 45 55 | +0·011 | 35 28 | 0·00 |
| 34 | γ Draconis | 2·4 | 17 53 8 | 0·000 | 38 29 | +0·04 |

| Observed | | | Assumed | | Computed | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $\varpi$ | $\rho_0$ | $\frac{d\rho}{dt}$ | $\Lambda v$ | $\Pi r_0 \frac{dr}{dt}$ | $\varpi$ | $\rho_0$ | $\frac{d\rho}{dt}$ | $\Delta\varpi$ | $\Delta\frac{d\rho}{dt}$ |
| ″ 0·268 | 3·73 | − 2·1? | 0 | 0 | ″ 0·210 | 4·76 | − 0·5 | ″ +0·058 | −1·6? |
| 0·028 | 35·7 | ... | − 12·5 | + 7·5 | ... | ... | +19·2 | ... | ... |
| 0·765 | 1·31 | ... | 0 | 0 | 0·909 | 1·10 | − 2·6 | −0·144 | ... |
| 0·132 | 7·52 | −15·9 | 0 | 0 | 0·188 | 5·33 | −14·5 | −0·056 | −1·4 |
| 0·046 | 21·7 | + 9·0 | 0 | 0 | 0·029 | 34·4 | + 8·7 | +0·017 | +0·3 |
| 0·128 | 7·81 | −12·4 | 0 | 0 | 0·069 | 14·5 | −18·7 | +0·059 | +6·3 |
| ... | ... | + 6·6 | − 75 | − 3·1 | 0·015 | 66·7 | ... | ... | ... |
| 0·123 | 8·13 | + 5·3 | 0 | 0 | 0·074 | 13·5 | + 8·6 | +0·049 | −3·3 |
| ... | ... | + 9·3 | 0 | 0 | 0·017 | 60·0 | +14·4 | ... | −5·1 |
| 0·181 | 5·53 | − 8·6 | 0 | 0 | 0·146 | 6·87 | −14·1 | +0·035 | +5·5 |
| 0·0? | large | ... | 0 | 0 | 0·001 | 701 | + 2·2 | 0·0? | ... |
| ... | .. | +11·0 | 0 | 0 | 0·018 | 56·8 | +14·2 | ... | −3·2 |
| ... | ... | − 4·1 | 0 | 0 | 0·001 | 948 | − 5·6 | ... | +1·5 |
| ... | ... | −11·0 | +196 | − 10·3 | 0·060 | 16·6 | ... | ... | ... |
| ... | ... | + 3·5 | 0 | 0 | 0·020 | 50·4 | + 9·6 | ... | −6·1 |
| 0·0? | large | −11·7 | 0 | 0 | 0·004 | 282 | −14·9 | 0·0? | +3·2 |
| 0·198 | 5·05 | + 6·1 | − 12·8 | − 0·9 | ... | ... | ... | ... | ... |
| ... | ... | + 4·1 | +168 | + 6·4 | 0·019 | 51·5 | ... | ... | ... |
| ... | ... | − 9·6 | + 50·3 | − 6·2 | 0·005 | 204 | ... | ... | ... |
| ... | ... | − 4·9 | + 14·8 | + 3·0 | 0·026 | 38·0 | ... | ... | ... |
| ... | ... | − 9·7 | + 49·1 | + 5·1 | 0·017 | 59·0 | ... | ... | ... |
| ... | ... | −11·5 | +206 | + 4·5 | 0·034 | 29·5 | ... | ... | ... |
| 0·043 | 23·3 | ... | 0 | 0 | 0·008 | 133 | −12·6 | +0·035 | ... |
| ... | ... | − 4·9 | + 1·5 | + 5·1 | 0·030 | 33·0 | ... | ... | ... |
| ... | ... | − 6·7 | +100 | + 5·0 | 0·022 | 43·6 | ... | ... | ... |
| ... | ... | − 9·0 | +185 | + 0·6 | 0·034 | 29·0 | ... | ... | ... |
| ... | ... | + 6·7 | +200 | + 3·6 | 0·038 | 26·0 | ... | ... | ... |
| ... | ... | − 3·8 | +100 | + 9·1 | 0·012 | 87·0 | ... | ... | ... |
| ... | ... | + 7·2 | +200 | + 5·1 | 0·036 | 28·1 | ... | ... | ... |
| ... | ... | − 4·6 | − 15·4 | + 4·7 | 0·010 | 97·0 | ... | ... | ... |
| ... | ... | − 0·4 | − 6·9 | − 1·9 | 0·065 | 15·4 | ... | ... | ... |
| ... | ... | + 7·9 | +230 | + 5·5 | 0·017 | 60·0 | ... | ... | ... |
| ... | ... | + 6·0 | +200 | + 6·5 | 0·016 | 61·0 | ... | ... | ... |
| 0·092 | 10·9 | − 2·5 | − 0·6 | + 0·5 | 0·150 | 6·67 | 0·0 | ... | ... |

| No. | Star | M | R.A. 1850 h m s | P.M. in R.A. s | N.P.D. 1850 ° ′ | P.M. in N.P.D. ″ |
|---|---|---|---|---|---|---|
| 35 | ε Pegasi | 2·4 | 21 36 49 | +0·003 | 80 49 | 0·00 |
| 36 | α Pegasi | 2·4 | 22 57 18 | +0·003 | 75 36 | +0·02 |
| 37 | α Cephei | 2·6 | 21 15 0 | +0·021 | 28 3 | −0·01 |
| 38 | γ Pegasi | 2·8 | 0 5 31 | 0·000 | 75 39 | +0·02 |
| 39 | γ Virginis | 2·8 | 12 34 4 | −0·037 | 90 38 | +0·05 |
| 40 | γ Aquilæ | 2·8 | 19 39 8 | +0·001 | 79 45 | 0·00 |
| 41 | δ Cygni | 2·9 | 19 40 17 | +0·006 | 45 14 | 0·00 |
| 42 | β Cygni | 3·0 | 19 24 40 | −0·002 | 62 21 | 0·00 |
| 43 | ζ Aquilæ | 3·1 | 18 58 31 | −0·006 | 76 21 | +0·07 |
| 44 | ι Ursæ Majoris | 3·2 | 8 48 55 | −0·047 | 41 22 | +0·28 |
| 45 | δ Andromedæ | 3·3 | 0 31 19 | +0·009 | 59 58 | +0·10 |
| 46 | η Cassiopeæ | 3·5 | 0 40 3 | +0·132 | 32 59 | +0·49 |
| 47 | 70 p. Ophiuchi | 4·3 | 17 57 53 | +0·015 | 87 28 | +1·12 |
| 48 | e Eridani | 4·4 | 3 13 55 | +0·270 | 133 39 | −0·75 |
| 49 | $o^2$ Eridani | 4·4 | 4 8 22 | −0·148 | 97 53 | +3·46 |
| 50 | δ Ursæ Minoris | 4·4 | 18 20 44 | +0·048 | 3 24 | −0·03 |
| 51 | σ Draconis | 4·7 | 19 32 38 | +0·096 | 20 36 | +1·79 |
| 52 | ζ Toucani | 5·0 | 0 12 12 | +0·273 | 155 45 | −1·16 |
| 53 | 61 Cygni | 5·0 | 21 0 11 | +0·342 | 51 59 | −3·11 |
| 54 | μ Cassiopeæ | 5·2 | 0 58 19 | +0·386 | 35 49 | +1·56 |
| 55 | ε Indi | 5·2 | 21 51 51 | +0·480 | 147 24 | +2·60 |
| 56 | Cephei 51 (Hev.) | 5·3 | 6 28 33 | −0·027 | 2 45 | +0·08 |
| 57 | 85 Pegasi | 5·8 | 23 54 21 | +0·067 | 63 43 | +0·95 |
| 58 | 3077 Bradley | 5·9 | 23 6 4 | +0·250 | 33 40 | −0·27 |
| 59 | 6 B. Cygni | 6·0 | 19 8 12 | −0·015 | 40 25 | −0·62 |
| 60 | Piazzi III. 242 | 6·5 | 3 57 35 | +0·017 | 52 20 | +0·15 |
| 61 | 1618 Groombridge | 6·5 | 10 2 6 | −0·139 | 39 48 | +0·50 |
| 62 | 1830 Groombridge | 6·5 | 11 44 19 | +0·344 | 51 12 | +5·70 |
| 63 | 21,185 Lalande | 7·5 | 10 55 8 | −0·044 | 53 2 | +4·66 |
| 64 | 9352 Lacaille | 7·5 | 22 56 10 | +0·567 | 126 43 | −1·31 |
| 65 | 34 Groombridge | 8·0 | 0 9 52 | +0·255 | 46 50 | −0·37 |
| 66 | 21258 Lalande | 8·5 | 10 58 0 | −0·386 | 45 42 | −1·36 |
| 67 | 17415 Oeltzen | 9·0 | 17 37 17 | −0·070 | 21 33 | +1·20 |
| 68 | 11677 Oeltzen | 9·5 | 11 12 0 | −0·507 | 23 20 | −0·21 |

| Observed | | | Assumed | | Compute | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $\varpi$ | $\rho_0$ | $\frac{d\rho}{dt}$ | $\Delta v$ | $\Pi r_0 \frac{dr}{dt}$ | $\varpi$ | $\rho_0$ | $\frac{d\rho}{dt}$ | $\Delta\varpi$ | $\frac{d\rho}{dt}$ |
| ″ | | | | | ″ | | | ″ | |
| ... | ... | − 4·9 | 0 | 0 | 0·009 | 106 | − 8·2 | ... | + 3·3 |
| ... | ... | − 8·8 | 0 | − 0·9 | 0·006 | 155 | ... | ... | ... |
| ... | ... | − 14·4 | 0 | 0 | 0·016 | 63·7 | − 14·2 | ... | − 0·2 |
| ... | ... | − 8·1 | + 136 | + 1·2 | 0·008 | 129 | ... | ... | ... |
| ... | ... | + 8·6 | + 31·3 | + 9·5 | 0·060 | 16·7 | ... | ... | ... |
| ... | ... | − 8·4 | 0 | 0 | 0·013 | 75·0 | − 15·5 | ... | + 7·1 |
| ... | ... | − 5·1 | − 60·9 | 0·0 | 0·012 | 80·0 | ... | ... | ... |
| ... | ... | − 4·9 | + 105 | + 7·7 | 0·008 | 119 | ... | ... | ... |
| ... | ... | − 7·9 | − 37·6 | + 7·0 | 0·020 | 50·0 | ... | ... | ... |
| 0·133 | 7·52 | ... | 0 | − 0·9 | ... | ... | + 7·0 | ... | ... |
| ... | ... | − 14·0 | + 143 | + 9·7 | 0·023 | 43·2 | ... | ... | ... |
| 0·154 | 6·49 | ... | 0 | 0 | 0·065 | 15·3 | − 4·4 | + 0·089 | ... |
| 0·160 | 6·25 | ... | 0 | 0 | 0·111 | 9·00 | − 17·1 | + 0·049 | ... |
| 0·136 | 7·35 | ... | 0 | 0 | 0·328 | 3·05 | + 17·6 | − 0·192 | ... |
| 0·194 | 5·16 | ... | + 424 | − 2·8 | ... | ... | + 8·6 | ... | ... |
| 0·034 | 29·4 | ... | 0 | 0 | 0·015 | 65·7 | − 12·4 | + 0·019 | ... |
| 0·255 | 3·92 | ... | + 43·6 | + 1·7 | ... | ... | − 7·6 | ... | ... |
| 0·057 | 17·5 | ... | + 795 | − 22·8 | ... | ... | + 5·8 | ... | ... |
| 0·441 | 2·27 | ... | 0 | 0 | 0·422 | 2·37 | − 10·5 | + 0·019 | ... |
| 0·342 | 2·92 | ... | 0 | 0 | 0·199 | 5·02 | − 2·5 | + 0·143 | ... |
| 0·215 | 4·65 | ... | + 100 | − 0·5 | ... | ... | + 10·8 | ... | ... |
| 0·027 | 37·0 | ... | 0 | 0 | 0·037 | 27·0 | + 1·6 | − 0·010 | ... |
| 0·050 | 20·0 | ... | 0 | 0 | 0·071 | 14·0 | − 2·0 | − 0·021 | ... |
| 0·185 | 5·40 | ... | 0 | 0 | 0·126 | 7·91 | − 5·8 | + 0·059 | ... |
| 0·482 | 2·07 | ... | 0 | + 0·1 | ... | ... | 0·0 | ... | ... |
| 0·016 | 62·5 | ... | 0 | 0 | 0·028 | 35·0 | + 8·9 | − 0·012 | ... |
| 0·322 | 3·11 | ... | 0 | − 0·3 | ... | ... | + 5·8 | ... | ... |
| 0·145 | 6·90 | ... | + 2459 | + 39·2 | ... | ... | − 4·2 | ... | ... |
| 0·501 | 2·00 | ... | + 70 | + 2·7 | ... | ... | − 12·2 | ... | ... |
| 0·285 | 3·51 | ... | + 1000 | − 6·1 | ... | ... | − 19·5 | ... | ... |
| 0·307 | 3·26 | ... | 0 | 0 | 0·195 | 5·14 | − 1·0 | + 0·112 | ... |
| 0·261 | 3·83 | ... | + 800 | − 4·0 | ... | ... | + 22·1 | ... | ... |
| 0·247 | 4·05 | ... | + 118 | + 2·7 | ... | ... | + 1·8 | ... | ... |
| 0·256 | 3·91 | ... | + 1600 | − 2·0 | ... | ... | − 45·9 | ... | ... |

This table contains the computations for all stars whose annual parallaxes have been ascertained, and of all stars whose radial velocities have been determined at Greenwich with a moderate degree of certainty.

With regard to the Greenwich observations of radial velocities published in the *Monthly Notices of the Royal Astronomical Society*, vols. xxxvi., xxxvii., xxxviii., xli., xlii., xliii., xliv., and xlv., the stars were divided into three classes: (1) those whose radial velocities can be depended on in consequence of the number and the agreement of the observations; (2) those whose radial velocities are less certain; and (3) those whose radial velocities cannot be depended on in consequence of the small number of the observations or of want of agreement among them.

Stars of the third class have not been considered in the above table; and indeed many stars of the second class have radial velocities assigned to them which are far from reliable.

Let us take as an example the star $\epsilon$ *Ursæ Majoris*, and collect all the observations of its radial velocity published in the volumes referred to above:

| Date. | Miles per sec. |
|---|---|
| 1877, May 2 | + 5·9 |
| 1879, May 21 | + 24·4 |
| „ June 9 | + 9·8 |
| 1880, May 22 | + 0·2 |
| „ June 4 | + 15·4 |
| 1883, July 13 | + 2·1 |
| „ Aug. 21 | + 24·8 |
| Mean | + 11·8 |

And dividing by 2·9 we have $\frac{d\rho}{dt} = +4{\cdot}1$ as adopted in the table; and consequently we have an elliptic orbit for the star.

But in vol. xlvi. of the *Monthly Notices*, published after the commencement of the present revision, we find that on Aug. 10, 1885, a radial velocity of $-41{\cdot}7$ miles per second was observed at Greenwich; so that $\epsilon$ *Ursæ Majoris* should be placed in the third class at present, and rejected.

This latter radial velocity has, however, been confirmed by Mr. G. M. Seabroke at Rugby, who found $-32$ miles per second (*Monthly Notices*, vol. xxxix., p. 453); so that $\frac{d\rho}{dt}$ may be about $-8$ instead of $+4{\cdot}1$. Now if the orbit of $\epsilon$ *Ursæ Majoris* be assumed circular, we would have $\varpi = 0''{\cdot}044$, $\rho_0 = 22{\cdot}8$, and $\frac{d\rho}{dt} = -7{\cdot}4$; and it thus appears that the orbit of this star is most probably circular, although our systematic computations require us to assume it to be elliptic.

This example has been given, not to detract from the value of the Greenwich observations of radial velocity, but to point out as clearly as possible that most of the results which have been obtained up to the present time cannot be regarded as even approximately final, and must therefore be accepted with great caution.

There is therefore no reason to be dissatisfied with the results of our systematic computations given in the table above; in the case of 37 stars observed for annual parallax, 21 have circular, 11 have moderately elliptic, and 5 have highly elliptic orbits;* in the case of 40 stars, including *Sirius*, observed for radial velocity, 14 have circular, 24 have moderately elliptic, and 2 have highly elliptic orbits.†

It will be noticed that stars observed for radial velocity do not, on the whole, give such good results as stars observed for annual parallax; one reason, that of uncertainty of observation, has just been discussed; another reason will, perhaps, be found in the uncertainty attending the very small proper motions attributed to many of these stars. In the first article it was considered right to omit all stars which have very small proper motions; but this restriction was removed in the computations above, and the results apparently justify its removal, as we cannot attribute to chance the circularity of the orbits of $\alpha$ *Orionis*, $\alpha$ *Cygni*, $\epsilon$ *Pegasi*, and $\gamma$ *Aquilæ*. The uncertainty, however, may exist, although we are not at present entitled to reject stars however small their proper motions. And a third reason will probably be found by combining the enormous distances of many of these stars with our present imperfect knowledge of the sidereal system. Therefore, by taking into consideration all the sources of error, we have no reason to be dissatisfied, as already said, with the general results we have obtained.

In an article "On the Theory of the Sidereal System," which was written by Mr. W. E. Plummer, and which appeared in *Copernicus*, No. 15, March 1882, we find that the formulæ of the original article were applied to stars whose radial velocities had been observed at Greenwich between the years 1875 and 1880. There were 90 of these stars, but the greater portion were rejected on account of their small proper motions, and a few were omitted as having been already examined in the original article, so that but 40 remained for computation.

Now of these 40 stars, 26 still belong to what we have termed the third class, 11 belong to the second class, and only 3 to the first class; and, rejecting the third class altogether, we find considerable differences between the remaining radial velocities obtained at that and the present time. For instance, $\frac{d\rho}{dt}$ for $\beta$ *Cassiopeæ* was then $+12{\cdot}8$; it is now $-0{\cdot}4$; and $\frac{d\rho}{dt}$ for $\alpha$ *Persei* was then

* Nos. 2, 52, 62, 64, and 68. † Nos. 39 and 43.

$+7{\cdot}9$; it is now $-9{\cdot}6$. In short, the data were not reliable, and disappointment was the consequence.

But, on the other hand, I have to thank Mr. Plummer for pointing out an error in the computation of 21185 *Lalande* given in the *Monthly Notices*, vol. xxxix. p. 132, which has of course been corrected in the table above, and for calling attention to the proper motions of the stars generally. As already stated, Mr. Main's proper motions have been systematically employed in the original and present articles; but Mr. Plummer used proper motions, or the means of proper motions, given by various authorities. By such procedure we might easily have found proper motions to suit such stars as $\gamma$ *Draconis*, $\iota$ *Ursæ Majoris*, 6 B. *Cygni*, 1618 Groombridge, and others, whose orbits are now very slightly elliptic, and thus have largely increased the number of circular orbits. What we really require is a careful determination of the proper motions of all stars whose annual parallaxes and radial velocities have been observed; and until this be done we shall adopt Mr. Main's proper motions as heretofore.

We have now passed through our tentative stage, and found a system which satisfies our principal stars, *Sirius*, *Arcturus*, *Capella*, *Vega*, *Procyon*, and *Altair* in both distant and radial velocity; which satisfies a number of stars in either distance or radial velocity; and which, upon the assumption of moderately elliptic orbits, satisfies the rest of the stars subjected to computation with but few exceptions.

It still remains to form equations of condition in order to find corrections to the adopted values of L, M, N, $\Pi$, and V; there will be twenty-one such equations depending upon annual parallax, and there will be fourteen depending upon radial velocity.

In the original article the formation of such equations depending upon annual parallax was fully discussed, and we need only reproduce the formulæ.

Let

$$S = \frac{\varpi\left(a\mathrm{V} + \frac{d\rho}{dt}\right)}{\mathrm{H} + \Pi\rho_0};$$

$$p = \frac{\nu\mathrm{L} - \lambda\mathrm{N}}{\mu\mathrm{N} - \nu\mathrm{M}};\ \log p = -10{\cdot}09515$$

$$q = \frac{\lambda\mathrm{M} - \mu\mathrm{L}}{\mu\mathrm{N} - \nu\mathrm{M}};\ \log q = -10{\cdot}19763$$

$$\mathrm{U} = \delta l + p\delta m + q\delta n - u(l + pm + qn);$$

$$\tfrac{1}{2}\frac{d\epsilon}{d\varpi} = \mathrm{V}(au - b + \mathrm{H}\Pi\mathrm{V}) + u\rho_0{}^2\mathrm{S}\Pi;$$

$$\tfrac{1}{2}\frac{d\epsilon}{d\mathrm{L}} = \mathrm{SU} + \varpi\Pi\mathrm{V}^2(l + pm + qn);$$

$$\tfrac{1}{2}\frac{d\epsilon}{d\mathrm{V}} = \varpi(au - b + \mathrm{H}\Pi\mathrm{V}) + a\mathrm{S}\Pi + \mathrm{V}\Pi^2 + \varpi\mathrm{H}\Pi\mathrm{V};$$

$$\tfrac{1}{2}\frac{d\epsilon}{d\Pi} = S\left(a\,V + \frac{d\rho}{dt}\right) + \varpi V^2(H + \Pi\rho_0);$$

$$A = \frac{\dfrac{d\epsilon}{dL}}{\dfrac{d\epsilon}{d\varpi}};\quad C = \frac{\dfrac{d\epsilon}{dV}}{\dfrac{d\epsilon}{d\varpi}};\quad E = \frac{\dfrac{d\epsilon}{d\Pi}}{\dfrac{d\epsilon}{d\varpi}};$$

then

$$A\,.\,\Delta L + C\,.\,\Delta V + E\,.\,\Delta\Pi + \Delta\varpi = 0,$$

is the equation for the determination of $\Delta L$, $\Delta V$, and $\Delta\Pi$, the corrections which must be added to the adopted values of L, V, and $\Pi$, where $\Delta\varpi$ is the difference between the observed and the computed parallax. And lastly $\Delta M = p\,.\,\Delta L$, $\Delta N = q\,.\,\Delta L$.

In order to form similar equations depending on $\Delta\frac{d\rho}{dt}$, the difference between the observed and the computed radial velocity, since

$$\frac{d\rho}{dt} = -u\rho_0,$$

we have

$$\Delta\frac{d\rho}{dt} = \frac{\Delta\varpi}{\varpi^2}\left(u - \varpi\frac{\Delta u}{\Delta\varpi}\right);$$

but

$$\frac{\Delta u}{\Delta\varpi} = \frac{du}{d\varpi} = \frac{u\rho_0{}^2\Pi}{H + \Pi\rho_0}{}^*;$$

so that

$$\Delta\frac{d\rho}{dt} = \frac{\Delta\varpi}{\varpi^2}\,.\,\frac{uH}{H + \Pi\rho_0},$$

or

$$\Delta\varpi = \Delta\frac{d\rho}{dt}\,.\,\frac{\varpi^2(H + \Pi\rho_0)}{uH}.$$

If, therefore, in the case of any star we multiply $\Delta\frac{d\rho}{dt}$ by the factor

$$\frac{\varpi^2(H + \Pi\rho_0)}{uH},$$

we have the equation

$$A\,.\,\Delta L + C\,.\,\Delta V + E\,.\,\Delta\Pi + \Delta\frac{d\rho}{dt}\,.\,\frac{\varpi^2(H + \Pi\rho_0)}{uH} = 0,$$

where A, C, and E are to be computed as before. This arrangement will permit the equations depending on annual parallax and radial velocity to be very simply treated together according to the method of least squares; and it will save very much labour when many stars are employed which may have been observed for both annual parallax and radial velocity.

We thus obtain the following equations depending on parallax:—

* See original article, p. 178.

*First Series.*

| No. | | | | | Weight. |
|---|---|---|---|---|---|
| 1 | −8·540 | ΔL+0·041 | ΔV+29·140 | ΔΠ=−0·058 | 3 |
| 3 | +4·747 | +0·097 | + 8·940 | =+0·144 | 3 |
| 4 | −0·196 | +0·019 | + 0·873 | =+0·056 | 3 |
| 5 | +0·036 | +0·002 | − 0·921 | =−0·017 | 3 |
| 6 | −0·063 | +0·006 | − 1·796 | =−0·059 | 3 |
| 8 | +0·030 | +0·008 | + 0·240 | =−0·049 | 3 |
| 10 | −0·615 | +0·014 | − 1·525 | =−0·035 | 3 |
| 11 | +0·001 | 0·000 | + 0·550 | = 0·000 | 1 |
| 16 | 0·000 | 0·000 | − 0·842 | = 0·000 | 1 |
| 23 | +0·021 | 0·000 | − 1·186 | =−0·035 | 3 |
| 46 | −0·008 | +0·006 | − 0·444 | =−0·089 | 2 |
| 47 | +0·054 | +0·013 | + 2·712 | =−0·049 | 2 |
| 48 | +0·106 | +0·032 | − 2·120 | =+0·192 | 2 |
| 50 | +0·051 | +0·001 | − 1·170 | =−0·019 | 2 |
| 53 | −0·345 | +0·042 | − 0·646 | =−0·019 | 3 |
| 54 | −0·005 | +0·020 | − 0·471 | =−0·143 | 2 |
| 56 | +0·356 | −0·011 | −19·560 | =+0·010 | 2 |
| 57 | +0·002 | +0·007 | − 0·520 | =+0·021 | 2 |
| 58 | −0·020 | +0·012 | − 0·505 | =−0·059 | 2 |
| 60 | +0·053 | +0·002 | − 1·192 | =+0·012 | 2 |
| 65 | +0·062 | ΔL+0·019 | ΔV− 0·890 | ΔΠ=−0·112 | 2 |

And similarly we obtain the following equations depending on radial velocity:—

*Second Series.*

| No. | | | | | Weight. |
|---|---|---|---|---|---|
| 1 | −8·540 | ΔL+0·041 | ΔV+29·140 | ΔΠ=+0·768 | 1 |
| 4 | −0·196 | +0·019 | + 0·873 | =+0·019 | 3 |
| 5 | +0·036 | +0·002 | − 0·921 | =+0·001 | 3 |
| 6 | −0·063 | +0·006 | − 1·796 | =−0·015 | 3 |
| 8 | +0.030 | +0·008 | + 0·240 | =−0·044 | 3 |
| 9 | +0·100 | +0·001 | − 2·000 | =+0·004 | 2 |
| 10 | −0·615 | +0·014 | − 1·525 | =−0·048 | 3 |
| 12 | +0·014 | +0·001 | − 0·936 | =−0·001 | 2 |
| 13 | 0·000 | 0·000 | + 0·536 | =−0·002 | 1 |
| 15 | −0·051 | +0·003 | + 1·450 | =−0·020 | 1 |
| 16 | 0·000 | 0·000 | − 0·842 | =+0·002 | 2 |
| 35 | −0·021 | +0·001 | − 0·666 | = 0·000 | 1 |
| 37 | +0·007 | +0·001 | − 0·770 | = 0·000 | 1 |
| 40 | −0·052 | ΔL 0·000 | ΔV− 1·585 | ΔΠ=+0·004 | 1 |

With reference to the weights adopted, a weight of 3 has been given to each star whose parallax is well known, or whose parallax is confirmed by its radial velocity,* and to each star whose radial velocity of the first class is confirmed by its parallax. Again, a weight of 2 has been given to each star whose unconfirmed parallax is less certain, and to each star whose unconfirmed radial velocity is of the first class. And, lastly, a weight of 1 has been given to each star whose parallax or radial velocity must be considered uncertain at present.

The following table has been drawn up according to this system:—

| | *Weights.* 3 | 2 | 1 |
|---|---|---|---|
| Parallax. | Sirius | $\eta$ Cassiopeæ | $\beta$ Centauri |
| | $\alpha$ Centauri | 70 p. Ophiuchi | $\alpha$ Cygni |
| | Arcturus | e Eridani | |
| | Capella | $\delta$ Ursæ Minoris | |
| | Vega | $\mu$ Cassiopeæ | |
| | Procyon | Cephei 51 (Hev.) | |
| | Altair | 85 Pegasi | |
| | Polaris | 3077 Bradley | |
| | 61 Cygni | Piazzi III. 242 | |
| | | 34 Groombridge | |
| Radial Velocity. | Arcturus | $\alpha$ Orionis | Sirius |
| | Capella | Aldebaran | Spica |
| | Vega | $\alpha$ Cygni | Regulus |
| | Procyon | | $\epsilon$ Pegasi |
| | Altair | | $\alpha$ Cephei |
| | | | $\gamma$ Aquilæ |

Proceeding by the method of least squares, the first series of equations are reduced to the following:—

$$
\begin{array}{llll}
+862{\cdot}9 & \Delta L + 0{\cdot}797 & \Delta V - 1872 & \Delta\Pi = +10{\cdot}81, \\
+0{\cdot}797 & \Delta L + 0{\cdot}1309 & \Delta V + 18{\cdot}62 & \Delta\Pi = +\ 0{\cdot}093, \\
-1872 & \Delta L + 18{\cdot}62 & \Delta V + 10015 & \Delta\Pi = -\ 3{\cdot}2;
\end{array}
$$

whence

$$
\begin{aligned}
\Delta L &= +0{\cdot}0158, \\
\Delta V &= +0{\cdot}380, \\
\Delta\Pi &= +0{\cdot}00165.
\end{aligned}
$$

Substituting these values of the corrections in the first

* As in the case of *Capella*, where the agreement of O. and C. in parallax may be said to be confirmed by the agreement of O. and C. in radial velocity.

series of equations, the sum of the squares of the errors is reduced from 0·121 to 0·099.

Again, proceeding by the method of least squares, the second series of equations are reduced to the following:

$$\begin{array}{llll} +76{\cdot}7 & \Delta L - 0{\cdot}457 & \Delta V - 242 & \Delta\Pi = -6{\cdot}32, \\ -\ 0{\cdot}457 & \Delta L + 0{\cdot}0076 & \Delta V + 1{\cdot}05 & \Delta\Pi = +0{\cdot}025, \\ -242 & \Delta L + 1{\cdot}05 & \Delta V + 941 & \Delta\Pi = +23{\cdot}2; \end{array}$$

whence

$$\Delta L = -0{\cdot}0431,$$
$$\Delta V = -1{\cdot}378,$$
$$\Delta\Pi = +0{\cdot}01507.$$

Substituting these values of the corrections in the second series of equations, the sum of the squares of the errors is reduced from 0·595 to 0·008.

But it is to be remarked that the results of the second series depend chiefly on *Sirius;* and when $-2{\cdot}1$ was assumed as the mean radial velocity of that star, it was not intended that the assumption should have any great weight in the final equations, much less that it should greatly influence them.

It therefore becomes necessary to remove *Sirius* from the second series, when the remaining equations give the following:

$$\begin{array}{llll} +3{\cdot}8 & \Delta L - 0{\cdot}110 & \Delta V + 7 & \Delta\Pi = +0{\cdot}23, \\ -0{\cdot}110 & \Delta L + 0{\cdot}0059 & \Delta V - 0{\cdot}14 & \Delta\Pi = -0{\cdot}006, \\ +7 & \Delta L - 0{\cdot}14 & \Delta V + 93 & \Delta\Pi = +0{\cdot}9; \end{array}$$

whence

$$\Delta L = +0{\cdot}051,$$
$$\Delta V = +0{\cdot}063,$$
$$\Delta\Pi = +0{\cdot}006.$$

Substituting these values of the corrections in the second series of equations, No. 1 being omitted, the sum of the squares of the errors are reduced from 0·005 to 0·004.

Lastly, combining both series, No. 1 being omitted from the second series, we have the equations

$$\begin{array}{llll} +866{\cdot}7 & \Delta L + \ 0{\cdot}687 & \Delta V - 1865 & \Delta\Pi = +11{\cdot}04, \\ +0{\cdot}687 & \Delta L + \ 0{\cdot}1368 & \Delta V + 18{\cdot}48 & \Delta\Pi = +\ 0{\cdot}087, \\ -1865 & \Delta L + 18{\cdot}48 & \Delta V + 10108 & \Delta\Pi = -\ 2{\cdot}3; \end{array}$$

whence

$$\Delta L = +0{\cdot}0194,$$
$$\Delta V = +0{\cdot}113,$$
$$\Delta\Pi = +0{\cdot}00315.$$

Now the quantities to be corrected are: *

$$L = -0{\cdot}8831$$
$$M = -0{\cdot}1439$$
$$N = -0{\cdot}4466$$
$$V = +9{\cdot}943$$
$$\Pi = +0{\cdot}00665$$

and applying the corrections next above to L, V, and Π, and determining the new values of M and N as in the original article, p. 184, we have as the corrected quantities:

$$\begin{array}{ll} L = -\ 0{\cdot}8637, & \log L = -\ 9{\cdot}93636 \\ M = -\ 0{\cdot}1670, & \log M = -\ 9{\cdot}22262 \\ N = -\ 0{\cdot}4756, & \log N = -\ 9{\cdot}67720 \\ V = +\ 10{\cdot}056, & \log V = +\ 11{\cdot}00243 \\ \Pi = +\ 0{\cdot}00980, & \log \Pi = +\ 7{\cdot}99123 \end{array}$$

The centre, therefore, lies in the direction of the point whose co-ordinates for the year 1850 are

$$\left.\begin{array}{ll} \text{R.A.} & 10^\circ\ 56' \\ \text{N.P.D.} & 61\ \ 36 \end{array}\right\}$$

This point is very near the first point adopted in the original article; and it may be said that all the work expended on the system since it was first sketched out was required for the determination of Π, the annual parallax of the centre.

Now ΠV is the angular motion of the Sun round the centre during one year, expressed in seconds of arc; and as the new value of ΠV is 0″·09855, the new length of the Annus Magnus, or period of general revolution, is 13,150,000 years.

Here we must rest awhile; annual parallaxes and radial velocities have agreed in giving almost the same corrections to the former values of the constants; and the question now arises as to whether the position of the centre has not been determined with greater accuracy than the direction of the Sun's motion.† Of course the time will come when the two problems must be combined, and when the assumption of the circularity of the solar orbit must be removed; but as the combined problem will contain seven unknown corrections, namely $\Delta L$, $\Delta M$, $\Delta V$, $\Delta \Lambda$, $\Delta \Pi$, $\Delta \lambda$, and $\Lambda \mu$, a large number of stars must be employed.

Lastly, putting perturbations aside, it cannot be assumed that the law of force holds good beyond a certain distance from the centre; the star-density on either side of a certain radius may vary as much as the star-density on either side of the galactic

* Original article, p. 185.

† The recent researches of Mr. Plummer (*Memoirs*, vol. xlvii. p. 327) on the motions of southern stars have at least removed the certainty assumed in the original article.

plane; and, indeed, considering the complexity of the general problem, we may be well satisfied with the definite results we have so easily obtained.

## *Note I.*

The proper motions employed in this article were taken from the lists of Professors Main and Stone in the *Memoirs of the R.A.S.*, vols. 19, 28, and 33, excepting:—

| No. | Star. | Authority. |
|---|---|---|
| 2 | α Argus | Stone, *Mem.*, vol. 42, p. 135. |
| 3 | α Centauri | Elkin „ 48, p. 14. |
| 11 | β Centauri | Stone „ 42, p. 139. |
| 48 | e Eridani | Elkin „ 48, p. 175. |
| 49 | o² Eridani | Gill „ „ 156. |
| 52 | ζ Toucani | Elkin „ „ 168. |
| 55 | ε Indi | „ „ „ 119. |
| 56 | Cephei 51 (Hev.) | *B.A.C.* |
| 57 | 85 Pegasi | „ |
| 58 | 3077 Bradley | *Copernicus*, No. 22, p. 201. |
| 59 | 6 B. Cygni | Argelander, *Dunsink Obs.*, Part V., p. 232. |
| 60 | Piazzi III. 242 | O. Struve, *M. N.*, vol. 41, p. 36. |
| 61 | 1618 Groombridge | Argelander, *Dunsink Obs.*, Part V., p. 187. |
| 62 | 1830 Groombridge | Argelander, *B.A.C.* |
| 63 | 21185 Lalande | Lynn. |
| 64 | 9352 Lacaille | Gould, *Mem.*, vol. 48, p. 140. |
| 65 | 34 Groombridge | *Nature* „ 43, p. 172. |
| 66 | 21258 Lalande | Lynn, *M. N.*, vol. 33, p. 102. |
| 67 | 17415 Oeltzen | „ „ 31, p. 42. |
| 68 | 11677 Oeltzen | Geelmuyden, *Astr. Nach.*, No. 2287. |

## *Note II.*

The following parallaxes were employed in the above article, the means of different results being taken when possible:

| No. | Star. | Parallax and Authority. |
|---|---|---|
| 1 | Sirius | 0″·23, Henderson, *Mem.*, vol. 11, p. 239. |
| | | 0·27, Abbe, *M. N.*, vol. 28, p. 6. |
| | | 0·193, Von Gylden. |
| | | 0·381, Gill and Elkin, *Mem.*, vol. 48, p. 187. |
| | | 0·268, Mean. |
| 2 | Canopus | 0·028, Elkin, *Mem.*, vol. 48, p. 183. |
| 3 | α Centauri | 0·913, Henderson and Maclear, *Mem.*, vol. 12, p. 370. |
| | | 0·919, Maclear, *Mem.*, vol. 20, p. 98. |
| | | 0·916, Mean from zenith distances. |

| No. | Star. | Parallax and Authority. |
|---|---|---|
| 3 | α Centauri | 0″·880, Moesta (at Santiago). |
| | | 0·512, Elkin, *M. N.*, vol. 41, p. 223. |
| | | 0·752, Gill and Elkin, *Mem.*, vol. 48, p. 186. |
| | | 0·765, Mean. |
| 4 | Arcturus | 0·127, Peters. |
| | | 0·138, Johnson, *M. N.*, vol. 17, p. 271. |
| | | 0·132, Mean. |
| 5 | Capella | 0·046, Peters. |
| 6 | Vega | 0·06, ? Airy, *Mem.*, vol. 10, p. 265. |
| | | 0·155, W. Struve, Peters, and O. Struve, *M. N.*, vol. 13, p. 74. |
| | | 0·103, Peters, *Cosmos*, vol. III., p. 261. |
| | | 0·13, Brünnow. |
| | | 0·141, Johnson, *M. N.*, vol. 17, p. 271. |
| | | 0·180*, A. Hall, " 43, p. 222. |
| | | 0·128 Mean. |
| 8 | Procyon | 0·123, Auwers. |
| 10 | Altair | 0·181, Struve, *Mem.*, vol. 12, p. 29. |
| 17 | Castor | 0·198, Johnson, *M. N.*, vol. 17, p. 271. |
| 23 | Polaris | 0·067, Peters. |
| | | 0·046, *Nature*, vol. 18, p 669. |
| | | 0·015, L. de Ball, *Observatory*, No. 101, p. 314. |
| | | 0·043, Mean. |
| 34 | γ Draconis | 0·092, *Nature*, vol. 18, p. 669. |
| 44 | ι Ursæ Maj. | 0·133, Peters. |
| 46 | η Cassiopeæ | 0·154, *Nature*. |
| 47 | 70 p. Ophiuchi | 0·16, Krüger. |
| 48 | e Eridani | 0·136, Elkin, *Mem.*, vol. 48, p. 178. |
| 49 | $o^2$ Eridan | 0·166, Gill, *Mem.*, vol. 48, p. 160. |
| | | 0·223, A. Hall, *Observatory*, October 1885. |
| | | 0·194, Mean. |
| 50 | δ Ursæ Min. | 0·034, L. de Ball, *Observatory*, No. 101, p. 314 |
| 51 | σ Draconis | 0·255, Brünnow. |
| 52 | ζ Toucani | 0·057, Elkin, *Mem.*, vol. 48, p. 171. |
| 53 | 61 Cygni | 0·374, Bessel corrected by Peters. |
| | | 0·349, Peters, *Cosmos*, vol. III., p. 260. |
| | | 0·553, Auwers, *M. N.*, vol. 23, p. 74. |

* Corrected to 0″·134 (*Nature*, vol. 35, p. 258).

| No. | Star. | Parallax and Authority. |
|---|---|---|
| 53 | 61 Cygni | 0″·402, Johnson, *Main's Practical and Sph. Astronomy*, p. 378. |
| | | 0·465, Ball, *M. N.*, vol. 40, p. 250. |
| | | 0·468 „ „ 41, p. 164. |
| | | 0·478*, A. Hall „ 43, p. 222. |
| | | 0·441, Mean. |
| | | By the application of photography to the determination of parallax, Professor Pritchard has just found 0″·440, *M. N.*, vol. 47, p. 87. |
| 54 | μ Cassiopeæ | 0·342, O. Struve. |
| 55 | ε Indi | 0·215, Gill and Elkin, *Mem.*, vol. 48, p. 187. |
| 56 | Cephei 51 (Hev.) | 0·027, L. de Ball, *Observatory*, No. 101, p. 314. |
| 57 | 85 Pegasi | 0·05, Brünnow. |
| 58 | 3077 Bradley | 0·205, Backlund, *M. N.*, vol. 43, p. 223. |
| | | 0·28, Von Gylden „ „ |
| | | 0·07, Brünnow. |
| | | 0·185, Mean. |
| 59 | 6 B Cygni | 0·482, Ball, *M. N.*, vol. 43, p. 222. |
| 60 | Piazzi III. 242 | 0·016, Ball (from distances), *M. N.*, vol. 41, p. 40. |
| 61 | 1618 Groombridge | 0·322, Ball, *M. N.*, vol. 45, p. 254. |
| 62 | 1830 Groombridge | 0·034, O. Struve, *M. N.*, vol. 10, p. 124. |
| | | 0·226, Peters „ 14, p. 138. |
| | | 0·141, Peters and Wichmann, *M. N.*, vol. 14, p. 138. |
| | | 0·18, Wichmann and Schluter, „ 13, p. 132. |
| | | 0·145, Mean. |
| 63 | 21185 Lalande | 0·501, Winnecke. |
| 64 | 9352 Lacaille | 0·285, Gill, *Mem.*, vol. 48, p. 154. |
| 65 | 34 Groombridge | 0·307, Auwers, *M. N.*, vol. 28, p. 97. |
| 66 | 21258 Lalande | 0·262, Auwers „ 23, p. 74. |
| | | 0·260, Krüger „ „ p. 172. |
| | | 0·261, Mean. |
| 67 | 17415 Oeltzen | 0·247, Krüger. *M. N.*, vol. 23, p. 172. |
| 68 | 11677 Oeltzen | 0·270, Geelmuyden from R.A. |
| | | 0·242 „ „ Decl. |
| | | 0·256, Mean, *Astr. Nach.*, No. 2287. |

| | | |
|---|---|---|
| 11 | β Centauri | Gill found a small negative parallax; hence the parallax must be very small. |
| 16 | α Cygni | In Herschel's *Outlines of Astronomy* (sixth edition) p. 593, the parallax is similarly taken to be very small. |

* Corrected to 0″·270 (*Nature*, vol. 35, p. 258).

## *Note III.*

The following radial velocities were adopted from the observations made at Greenwich:—

| FIRST CLASS. | | | SECOND CLASS. | | |
|---|---|---|---|---|---|
| No. | Star. | Miles per Sec. | No. | Star. | Miles per Sec. |
| 4 | α Boötis | −46·0 | 13 | α Virginis | −11·9 |
| 5 | α Aurigæ | +26·0 | 15 | α Leonis | +10·1 |
| 6 | α Lyræ | −36·1 | 18 | ε Ursæ Maj. | +11·8 |
| 7 | β Orionis | +19·1 | 19 | α Persei | −27·7 |
| 8 | α Canis Min. | +15·5 | 20 | β Tauri | −14·3 |
| 9 | α Orionis | +26·9 | 22 | β Ceti | −33·5 |
| 10 | α Aquilæ | −24·9 | 24 | α Arietis | −14·2 |
| 12 | α Tauri | +32·0 | 25 | γ Cassiop. | −19·3 |
| 14 | β Gemin. | −31·8 | 26 | γ Leonis | −26·2 |
| 16 | α Cygni | −34·1 | 27 | ζ Ursæ Maj. | +19·3 |
| 17 | α Gemin. | +17·8 | 28 | α Ophiuchi | −10·9 |
| 21 | α Androm. | −28·2 | 30 | γ Cygni | −13·5 |
| 29 | α Coronæ | +20·7 | 31 | β Cassiop. | − 1·2 |
| 36 | α Pegasi | −25·5 | 32 | β Ursæ Maj. | +22·9 |
| | | | 33 | γ Ursæ Maj. | +17·5 |
| | | | 34 | γ Draconis | − 7·2 |
| | | | 35 | ε Pegasi | −14·3 |
| | | | 37 | α Cephei | −41·8 |
| | | | 38 | γ Pegasi | −23·4 |
| | | | 39 | γ Virginis | +25·0 |
| | | | 40 | γ Aquilæ | −24·3 |
| | | | 41 | δ Cygni | −14·7 |
| | | | 42 | β Cygni | −14·3 |
| | | | 43 | ζ Aquilæ | −23·0 |
| | | | 45 | δ Androm. | −40·6 |

## *Note IV.*

The radial velocity of *Sirius* and its curve of variation have been deduced from the following observations made at Greenwich, and given in the *Monthly Notices*, vol. xlv., p. 283:

| Opposition of | Miles per Sec. | Opposition of | Miles per Sec. |
|---|---|---|---|
| 1875–76, 1876–77 | +21·1 | 1881–82 | + 2·1 |
| 1877–78 | +23·0 | 1882–83 | − 4·7 |
| 1879–80 | +15·1 | 1883–84 | −19·4 |
| 1880–81 | +11·3 | 1884–85 | −21·5 |

But Dr. Huggins found +29·4 for about the opposition of 1868, and +20 for about the opposition of 1872, so that we have the following curve:


Rad. velocity +

Assuming a mean value of − 6 at the opposition of 1882–83, or early in the year 1883, and dividing by 2·9, we have −2·1 as the mean radial velocity of *Sirius*.

*Jamaica:* 1887, *March* 26.

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## *Observations of Comets and of Sappho* (80) *Harrow.*
## By G. L. Tupman.

*Revised Geocentric places of Comet* 1884 *III.* (*Wolf*).
(*Monthly Notices R.A.S.*, xlv. 403.)

| 1884–5. | Greenwich Mean Time. h m s | App. R.A. h m s | App. Decl. ° ′ ″ | Log. Δ. | Star. |
|---|---|---|---|---|---|
| Sept. 24 | 10 38 0 | 21 17 23·36 | +20 36 20·9 | 9·9036 | 1 |
| 25 | 9 46 4 | 21 17 58·81 | +20 9 42·6 | 9·9030 | 2 |
| 27 | 10 45 50 | 21 19 22·76 | +19 12 37·4 | 9·9019 | 3 |
| Oct. 4 | 9 17 52 | 21 25 33·82 | +15 51 52·0 | 9·9014 | 4 |
| | 9 59 47 | 21 25 35·90 | +15 51 1·1 | 9·9014 | 4 |
| | 10 23 34 | 21 25 36·89 | +15 50 35·6 | 9·9014 | 4 |
| 13 | 11 29 16 | 21 36 55·31 | +11 24 18·8 | 9·9072 | 5 |
| 22 | 9 30 22 | 21 51 21·09 | + 7 12 33·6 | 9·9200 | 6 |
| 26 | 10 4 32 | 21 58 49·15 | + 5 26 35·6 | 9·9277 | 7 |
| Nov. 7 | 10 27 53 | 22 23 57·02 | + 0 49 41·1 | 9·9566 | 8 |
| 8 | 9 40 20 | 22 26 7·26 | + 0 30 21·7 | 9·9593 | 9 |
| 18 | 9 41 0 | 22 49 39·28 | − 2 22 34·2 | 9·9890 | 10 |
| 19 | 6 19 34 | 22 51 45·38 | − 2 35 6·7 | 9·9918 | 10 |
| 20 | 9 28 34 | 22 54 31·77 | − 2 50 55·4 | 9·9954 | 11 |
| 21 | 5 56 32 | 22 56 37·57 | − 3 2 30·8 | 9·9981 | 12 |
| Dec. 9 | 6 34 15 | 23 42 25·41 | − 5 45 27·5 | 0·0589 | 13 |
| 15 | 6 1 59 | 23 57 52·08 | − 6 9 13·4 | 0·0796 | 14 |
| Jan. 7 | 6 48 36 | 0 56 56·32 | − 5 53 8·2 | 0·1618 | 15 |
| | 6 48 36 | 0 56 56·30 | − 5 53 10·6 | 0·1618 | 16 |
| Feb. 5 | 6 56 43 | 2 8 27·96 | − 3 9 17·7 | 0·2538 | 17 |

The times have not been corrected for aberration.

*Comet* 1885 *II.* (*Brooks*).
(*Monthly Notices*, xlvi. 123.)

| 1885. | Greenwich Mean Time. h m s | App. R.A. h m s | Lfp. | App. Decl. ° ′ ″ | Lfp. | Star. |
|---|---|---|---|---|---|---|
| Sept. 6 | 9 54 15 | 14 3 47·40 | +8·719 | +38 24 18·7 | +9·847 | 18 |
| 9 | 9 29 21 | 14 21 28·30 | +8·730 | +39 38 44·1 | +9·808 | 19 |
| 11 | 9 28 15 | 14 33 55·00 | +8·736 | +40 23 9·7 | +9·795 | 20 |
| 13 | 9 42 43 | 14 46 53·56 | +8·738 | +41 3 29·9 | +9·806 | 21 |
| | 9 42 43 | 14 46 53·53 | +8·738 | +41 3 25·4 | +9·806 | 22 |

Some small errors were discovered in the reductions.

## Comet 1886 I. (Fabry).

| | | ☄−★ Δα | ☄−★ Δδ | Comp. | ☄α | Par. | ☄δ | Par. | Star. |
|---|---|---|---|---|---|---|---|---|---|
| 1885. | h m s | m s | ′ ″ | | h m s | | ° ′ ″ | | |
| Dec. 7 | 10 26 50 | −0 28·70 | + 1 52·0 | 9 | 0 24 59·91 | +[8·513] | +20 52 29·8 | +[9·762] | 23 |
| 10 | 10 5 1 | −1 28·31 | − 1 1·1 | 14 | 0 18 36·78 | +[8·505] | +20 48 19·8 | +[9·761] | 24 |
| 27 | 9 43 17 | −0 6·58 | + 0 22·8 | 11 | 23 50 8·68 | +[8·604] | +20 43 13·1 | +[9·803] | 25 |
| 1886. | | | | | | s | | | |
| Jan. 26 | 6 45 32 | −2 30·07 | + 0 6·6 | 7 | 23 26 54·35 | +·18 | +22 51 22·2 | + 2·8 | 26 |
| 28 | 6 49 48 | −0 40·61 | + 0 9·3 | 10 | 23 26 11·05 | +·19 | +23 7 14·3 | + 2·9 | 27 |
| 30 | 6 32 34 | +0 10·54 | − 0 3·5 | 9 | 23 25 32·69 | +·18 | +23 24 5·8 | + 2·8 | 28 |
| 31 | 7 14 34 | −0 45·42 | + 4 7·7 | 8 | 23 25 13·99 | +·21 | +23 33 7·1 | + 2·2 | 29 |
| Feb. 2 | 6 30 41 | −1 4·01 | − 5 8·7 | 8 | 23 24 41·08 | +·20 | +23 51 15·0 | + 3·0 | 30 |
| 10 | 7 7 16 | +0 24·67 | − 3 20·3 | 6 | 23 22 58·83 | +·24 | +25 14 45·2 | + 3·4 | 31 |
| 25 | 7 32 57 | −0 56·58 | − 2 25·9 | 8 | 23 21 0·09 | +·27 | +28 33 59·1 | + 4·1 | 32 |
| 26 | 7 0 43 | −1 41·15 | − 4 34·1 | 6 | 23 20 52·23 | +·27 | +28 48 50·4 | + 4·0 | 33 |
| 27 | 6 52 45 | −1 0·84 | −11 33·5 | 3 | 23 20 45·29 | +·28 | +29 4 18·3 | + 4·0 | 34 |
| | 6 56 34 | +2 18·31 | + 1 22·4 | 1 | 23 20 44·71 | +·28 | +29 4 9·6 | + 4·0 | 35 |
| Mar. 3 | 7 1 3 | +1 21·62 | + 3 27·3 | 6 | 23 20 15·99 | +·29 | +30 8 33·2 | + 4·2 | 36 |
| 8 | 7 11 20 | +0 18·48 | −11 40·3 | 6 | 23 19 33·73 | +·30 | +31 33 47·9 | + 4·7 | 37 |
| 9 | 7 5 34 | −0 19·29 | + 0 46·6 | 11 | 23 19 24·35 | +·30 | +31 51 19·1 | + 4·7 | 38 |
| 11 | 7 14 57 | +0 34·94 | −10 30·5 | 6 | 23 19 4·62 | +·30 | +32 27 6·5 | + 5·0 | 39 |
| 31 | 7 53 9 | +0 33·00 | + 0 30·8 | 5 | 23 18 3·43 | +·34 | +38 22 52·8 | + 8·5 | 40 |
| Apr. 6 | 8 17 53 | +2 7·03 | − 4 18·8 | 9 | 23 23 3·89 | +·35 | +39 41 26·7 | +10·7 | 41 |

December 23.—Comet very much brighter; fully 2′ diameter.

December 27.—Comet bright; nucleus sub-stellar.

January 26.—Very bright, nearly 6 mag. More than 3′, perhaps 5′ diameter; with bright central condensation, not stellar. Ring Micrometer used Dec. 7, to Jan. 30; Crossed Bars afterwards.

March 9.—Faint; very low. March 31.—Bright although so very low.

April 6.—Bright; only $5\frac{1}{2}$° above the horizon. April 9. See *Ast. Nach.* 2723.

*Comet* 1886 *II.* (*Barnard.*)

| | G.M.T. | Δα (−*) | Δδ (−*) | Comp. | α | Par. | δ | Par. | Star. |
|---|---|---|---|---|---|---|---|---|---|
| 1885. | h m s | m s | ′ ″ | | h m s | | ° ′ ″ | ″ | |
| Dec. 27 | 10 7 38 | +0 59·22 | +10 56·3 | 7 | 3 22 31·44 | +·07 | + 7 31 54·2 | +3·8 | 42 |
| 1886. Jan. 28 | 7 11 5 | +0 14·48 | + 0 20·2 | 9 | 2 21 21·62 | +·07 | +13 27 33·9 | +2·8 | 43 |
| Feb. 1 | 6 54 42 | −0 3·41 | + 0 45·8 | 11 | 2 16 28·49 | +·08 | +14 19 8·1 | +3·2 | 44 |
| 2 | 7 2 12 | −1 11·48 | +14 1·2 | 5 | 2 15 20·42 | +·09 | +14 32 23·5 | +3·2 | 45 |
| 26 | 7 25 36 | +1 0·58 | − 4 28·5 | 8 | 1 57 43·99 | +·19 | +20 19 54·9 | +3·1 | 46 |
| Mar. 3 | 7 15 22 | +0 6·97 | + 7 57·1 | 7 | 1 55 53·04 | +·20 | +21 41 10·3 | +3·2 | 47 |
| 8 | 7 29 43 | −0 43·83 | +15 57·9 | 5 | 1 54 27·41 | +·22 | +23 6 28·9 | +3·3 | 48 |
| 9 | 7 21 22 | −1 0·56 | − 8 14·4 | 6 | 1 54 12·17 | +·22 | +23 23 57·4 | +3·3 | 49 |
| 11 | 7 28 48 | −1 0·38 | + 6 17·8 | 6 | 1 53 45·47 | +·23 | +23 59 44·7 | +3·3 | 50 |
| Apr. 3 | 9 0 56 | +0 42·22 | − 2 55·9 | 8 | 1 49 52·44 | +·25 | +31 48 53·1 | +4·8 | 51 |
| 6 | 8 39 42 | −0 16·87 | − 3 35·2 | 9 | 1 49 8·62 | +·26 | +32 57 43·8 | +4·9 | 52 |
| 8 | 9 20 14 | +1 31·02 | −10 37·3 | 7 | 1 48 33·99 | +·23 | +33 45 17·9 | +5·3 | 53 |
| 11 | 8 50 49 | +1 3·82 | +12 34·8 | 9 | 1 47 33·84 | +·26 | +34 55 57·8 | +5·4 | 54 |
| 15 | 9 5 8 | −2 21·39 | − 3 7·7 | 8 | 1 45 51·57 | +·25 | +36 30 48·0 | +5·9 | 55 |

December 27.—Comet pretty bright; not so bright as Fabry's; diam. 90″; nucleus sub-stellar, admitting of accurate observation. Ring Micrometer used Dec. 27, and Jan. 28; Crossed Bars afterwards.

January 28.—Diameter 90″. Coma extended in direction 120° or 130°.

February 1.—Diameter 90″. Stellar nucleus (?) of 9½ or 10 mag.

March 9.—Comet large, more than 2′ diam., perhaps 3′; very low.

April 3.—Very bright, although very low, may be 5 mag.; at least 3′ diameter.

April 15.—Comet faint owing to ☾ and haze.

*Comet* 1886 *V.* (*Brooks* I.)

| 1886. | G.M.T. h m s | ☄−* Δα m s | ☄−* Δδ ′ ″ | Comp. | ☄α h m s | Par. | ☄δ ° ′ ″ | Par. ″ | Star. |
|---|---|---|---|---|---|---|---|---|---|
| May 6 | 10 27 27 | −3 18·48 | − 7 6·8 | 9 | 1 27 21·84 | +·01 | +57 16 30·5 | +6·4 | 56 |
| 15 | 9 48 27 | −0 37·07 | − 4 30·1 | 10 | 2 19 35·61 | +·11 | +49 58 53·3 | +6·9 | 57 |
| 18 | 9 40 18 | +0 52·56 | − 5 19·4 | 6 | 2 34 30·13 | +·12 | +46 59 22·0 | +6·9 | 58 |
| | 9 49 34 | +0 32·03 | + 7 4·4 | 5 | 2 34 31·46 | +·12 | +46 58 58·0 | +6·9 | 59 |
| | 9 49 34 | +0 21·26 | + 6 57·0 | 5 | 2 34 31·59 | +·12 | +46 58 57·7 | +6·9 | 60 |
| 20 | 10 24 35 | −0 5·17 | +11 42·8 | 7 | 2 43 24·11 | +·05 | +44 53 23·6 | +7·1 | 61 |

May 6.—Comet is about 9 mag. 2′ diameter, with central condensation but no visible nucleus (4½-inch refractor).

May 20.—Very near the horizon, must be 5 or 6 mag.

*Comet* 1886 *IX.* (*Barnard-Hartwig.*)

| | G.M.T. | ☄ − ✱ Δα | ☄ − ✱ Δδ | Comp. | ☄ α | Par. | ☄ δ | Par. | Star. |
|---|---|---|---|---|---|---|---|---|---|
| 1886. | h m s | m s | ′ ″ | | h m s | s | ° ′ ″ | ″ | |
| Dec. 19 | 5 31 27 | −0 14·77 | +5 40·2 | 13 | 18 17 3·15 | +·33 | +12 4 17·1 | +5·8 | 62 |
| 23 | 5 23 15 | +1 13·38 | +3 30·0 | 6 | 18 46 5·93 | +·29 | + 9 26 41·6 | +5·4 | 63 |
| | 5 33 49 | −1 56·16 | −4 58·4 | 5 | 18 46 9·50 | +·30 | + 9 26 23·6 | +5·4 | 64 |
| 25 | 5 32 43 | +0 50·08 | −0 44·1 | 17 | 18 58 53·69 | +·28 | + 8 7 9·9 | +5·2 | 65 |
| | 5 34 0 | −0 7·71 | −0 48·3 | 17 | 18 58 54·03 | +·28 | + 8 7 3·9 | +5·2 | 66 |
| 27 | 5 25 16 | −0 34·42 | +5 42·0 | 13 | 19 10 32·71 | +·27 | + 6 49 14·1 | +5·1 | 67 |
| 30 | 5 56 24 | +0 23·84 | +7 47·1 | 9 | 19 26 25·12 | +·26 | + 4 54 52·5 | +4·9 | 68 |
| 31 | 5 37 26 | −0 29·88 | −5 38·9 | 10 | 19 31 11·90 | +·25 | + 4 18 45·9 | +4·9 | 69 |
| 1887. | | | | | | | | | |
| Jan. 5 | 5 35 31 | −0 13·08 | +4 34·94 | 15 | 19 52 45·40 | +·23 | + 1 26 24·3 | +4·6 | 70 |

December 18.—Comet very bright, circular, nucleus 15″ to 20″, diminishing to a stellar object as clouds pass over it. Coma extensive, perhaps 10′ diam. Tail 40′, perhaps 60′.

December 19.—Nucleus stellar, 7 mag. Coma $20^s$ in R.A. Air very thick, foggy.

December 20.—☄ = ε Aquilæ exactly. Tail 7° towards 110 Herculis.

December 25.—Nucleus stellar, small.

December 30.—Nucleus not so distinct.

December 31.—Still stellar.

*Comet* 1887 . . . (*Barnard, May* 12).

| 1887. | G.M.T. h m s | ☄ − ✱ Δα m s | Δδ ′ ″ | Comp. | ☄ α h m s | Par. s | ☄ δ ° ′ ″ | Par. ″ | Star. |
|---|---|---|---|---|---|---|---|---|---|
| June 12 | 11 38 22 | −1 46·24 | + 3 53·0 | 11, 6 | 16 11 0·02 | +·20 | −8 43 40·3 | +19·1 | 71 |
| 15 | 11 42 49 | +1 16·66 | | 13 | 16 17 43·99 | +·24 | | | 72 |
| | 11 42 49 | | − 2 14·5 | 5 | | | −6 29 54·0 | +18·5 | 73 |
| 17 | 11 51 47 | −0 35·36 | + 7 21·8 | 7 | 16 22 15·21 | +·28 | −5 4 15·2 | +18·0 | 74 |
| 19 | 11 53 55 | −1 20·24 | −10 10·1 | 8 | 16 26 43·78 | +·19 | −3 43 12·5 | +18·0 | 75 |
| 22 | 11 5 45 | +0 44·24 | + 1 40·7 | 4, 2 | 16 33 29·14 | +·13 | −1 48 14·6 | +17·2 | 76 |

Comet faint and small, condensed excentrically, admitting of pretty accurate observation (18-inch reflector). 11 or 12 mag. Ring Micrometer used, except on June 12.

*Sappho* (80)

| 1887 | G.M.T. h m s | Δα m s | Δδ ′ ″ | Comp. | (80) α h m s | Par. s | (80) δ ° ′ ″ | Par. ″ | Star. |
|---|---|---|---|---|---|---|---|---|---|
| Jan. 5 | 11 1 19 | −0 49·77 | − 4 42·5 | 10 | 7 8 13·90 | +·08 | +8 50 44·3 | + 4·27 | 77 |

Observed with the 18-inch reflector and bars carefully oriented.
The small corrections have been applied to all the above observations.

*Mean Places of the Comparison Stars.*

| | | h m s | ° ′ ″ | Mer. Obs. | Reductions to App. Place. s | ″ |
|---|---|---|---|---|---|---|
| | | | 1884·0. | | | |
| 1 | D.M. + 20°·4902 | 21 18 32·58 | + 20 29 10·6 | Harrow 4 | | |
| 5 | L.L. 42432 | 21 40 16·20 | + 11 20 44·9 | „ 4 | | |
| 6 | Lamont 6182 | 21 48 21·87 | + 7 15 42·3 | Strassburg 2 | | |
| | | 21·90 | 41·8 | Harrow 3 | | |
| 7 | {P XXI. 390 / Santini 1537} | 21 59 52·37 | + 5 24 9·1 | „ 3 | | |
| 8 | Lamont 8848 | 22 22 57·84 | + 0 44 12·4 | „ 2 | | |
| 9 | L.L. 44036 | 22 26 45·64 | + 0 30 26·2 | „ 2 | | |
| 10 | Lamont 9034 | 22 51 6·96 | – 2 28 20·6 | „ 4 | | |
| 11 | W.B. 1110 | 22 64 37·81 | – 2 50 10·8 | „ 3, 4 | | |
| 12 | L.L. 45064 | 22 56 46·10 | – 3 5 14·8 | „ 3, 4 | | |
| 13 | W.B. 821 | 23 41 54·84 | – 5 53 1·9 | Strassburg 2 | | |
| 14 | W.B. 1152 | 23 57 20·83 | – 6 6 24·8 | „ 2 | | |
| | | 20·84 | 23·5 | Harrow 4 | | |
| | | | 1885·0. | | | |
| 15 | W.B. 998 | 0 58 34·85 | – 5 55 17·1 | Harrow 2, 3 | | |
| 16 | W.B. 1003 | 0 58 47·84 | – 5 56 19·2 | „ 3 | | |
| 17 | Schj. 649 | 2 7 44·27 | – 3 10 35·3 | „ 2 | | |
| | | 43·95 | 38·5 | Strassburg 1 | | |
| 18 | W.B. 77, 78 | 14 5 39·86 | + 38 32 37·9 | Harrow 3 | | |
| 19 | W.B. 451 | 14 22 11·57 | + 39 38 47·3 | „ 3 | | |
| 20 | W.B. 681–2 | 14 33 33·27 | + 40 31 8·6 | „ 6 | | |
| 21 | W.B. 960 | 14 45 39·14 | + 40 59 50·5 | „ 5 | | |
| 22 | W.B. 973 | 14 47 3·36 | + 41 10 21·1 | „ 5 | | |
| 23 | D.M. + 20°, 52 | 0 25 25·17 | + 20 50 12·8 | „ 2 | + 3·44 | + 25·0 |
| 24 | D.M. + 20°, 39 | 0 20 1·80 | + 20 48 55·7 | „ 3 | + 3·36 | + 25·2 |
| 25 | D.M. + 20°, 5397 | 23 50 12·36 | + 20 42 24·8 | „ 4 | + 2·90 | + 25·4 |
| | | | 1886·0. | | | |
| 26 | D.M. + 22°, 4865 | 23 29 25·05 | + 22 51 12·6 | Harrow 2 | – 0·63 | + 3·0 |
| 27 | D.M. + 22°, 4856 | 23 26 52·20 | + 23 7 4·1 | B.B. VI. 1 | – 0·66 | + 2·7 |
| | | 52·42 | 0·3 | Harrow 1 | | |
| 28 | D.M. + 23°, 4755 | 23 25 22·83 | + 23 24 6·8 | „ 3 | – 0·68 | + 2·5 |
| 29 | L.L. 46081 | 23 26 0·09 | + 23 28 57·0 | „ 2 | – 0·68 | + 2·4 |
| 30 | D.M. + 23°, 4756 | 23 25 45·79 | + 23 56 21·5 | „ 2 | – 0·70 | + 2·2 |
| 31 | W.B. 445 – 6 | 23 22 34·92 | + 25 18 4·4 | „ 4, 3 | – 0·76 | + 1·1 |
| 32 | W.B. 423 | 23 21 56·67 | + 28 36 25·0 | „ 2 | – 0·81 | – 0·9 |
| 33 | L.L. 45957 | 23 22 34·19 | + 28 53 25·6 | „ 3 | – 0·81 | – 1·1 |

| | | | 1885·0. | Mer. Obs. | Reductions to App. Place. |
|---|---|---|---|---|---|
| | | h m s | ° ′ ″ | | s ″ |
| 34 | W.B. 421 | 23 21 46·94 | +29 15 53·0 | „ 2 | −0·81 − 1·2 |
| 35 | L.L. 45821 | 23 18 27·22 | +29 2 48·5 | Armagh₂ 5, 8 | −0·82 − 1·3 |
| 36 | L.L. 45839 | 23 18 55·18 | +30 5 7·8 | Harrow 2 | −0·81 − 1·9 |
| 37 | L.L. 45845 | 23 19 16·05 | +31 45 31·0 | „ 2 | −0·80 − 2·8 |
| 38 | L.L. 45857 | 23 19 44·43 | +31 50 34·6 | Radcliffe 3 | −0·79 − 2·8 |
| | | 44·60 | 36·0 | Armagh 1, 5 | |
| | | 44·41 | 33·9 | Harrow 1 | |
| 39 | W.B. 346 | 23 18 30·47 | +32 37 40·1 | „ 2 | −0·79 − 3·1 |
| 40 | W.B. 328 | 23 17 31·11 | +38 22 28·3 | „ 3, 4 | −0·68 − 6·3 |
| 41 | W.B. 402 | 23 20 57·38 | +39 45 52·6 | „ 2 | −0·52 − 7·1 |
| | | | 1885·0. | | |
| 42 | W.B. 344 | 3 21 28·21 | + 7 20 52·5 | Harrow 3, 4 | +4·01 + 5·4 |
| | | | 1886·0. | | |
| 43 | W.B. 311 | 2 21 6·95 | +13 27 18·9 | Harrow 2 | +0·19 − 5·2 |
| 44 | D.M. + 14°, 386 | 2 16 31·79 | +14 18 27·3 | „ 3, 2 | +0·11 − 5·0 |
| 45 | D.M. + 14°, 386 | 2 16 31·79 | +14 18 27·3 | „ 3, 2 | +0·11 − 5·0 |
| 46 | D.M. + 20°, 327 | 1 56 43·73 | +20 24 27·8 | „ 3, 2 | −0·32 − 4·4 |
| 47 | W.B. 1290 | 1 55 46·45 | +21 33 17·7 | „ 2 | −0·38 − 4·5 |
| 48 | L.L. 3715 | 1 55 11·69 | +22 50 34·6 | Armagh₂ 2, 3 | −0·44 − 4·6 |
| | | 11·67 | 36·8 | Harrow 2 | |
| 49 | D.M. + 23°, 271 | 1 55 13·17 | +23 32 16·4 | „ 2 | −0·44 − 4·6 |
| 50 | W.B. 1263 | 1 54 46·31 | +23 53 31·6 | Armagh₂ 2, 3 | −0·46 − 4·7 |
| 51 | W.B. 1095 | 1 49 10·83 | +31 51 54·8 | Harrow 3, 2 | −0·61 − 5·8 |
| 52 | W.B. 1106 | 1 49 26·10 | +33 1 25·0 | „ 2 | −0·61 − 6·0 |
| 53 | W.B. 1047 | 1 47 3·58 | +33 56 1·4 | „ 3 | −0·61 − 6·2 |
| 54 | L.L. 3415 | 1 46 30·62 | +34 43 29·5 | „ 2 | −0·60 − 6·5 |
| 55 | L.L. 3476 | 1 48 13·57 | +36 34 0·6 | Glasgow 3 | −0·59 − 6·8 |
| | | 13·52 | 2·6 | Armagh₂ 1 | |
| | | 13·55 | 3·8 | Harrow 2 | |
| 56 | B.A.C. 482 | 1 30 40·76 | +57 23 47·0 | Radcliffe 4, 3 | −0·46 − 9·7 |
| | | 40·87 | 46·3 | Gr. 1860 4, 2 | |
| | | 40·66 | 47·5 | Kr. Z. 331 1 | |
| 57 | 66 Androm. | 2 20 13·03 | +50 3 33·4 | Gr. 1864 3 | −0·35 −10·0 |
| 58 | L.L. 4902 | 2 33 37·88 | +47 4 51·5 | Harrow 3 | −0·31 −10·1 |
| 59 | D.M. + 46°, 609 | 2 33 59·73 | +46 52 3·7 | „ 3 | −0·30 −10·1 |
| 60 | D.M. + 46°, 610 | 2 34 10·63 | +46 52 10·8 | „ 3 | −0·30 −10·1 |
| 61 | L.L. 5203 | 2 43 29·52 | +44 41 51·3 | „ 5 | −0·25 −10·5 |

| | | R.A. 1886·0 | Decl. 1886·0 | Mer. Obs. | Reductions to App. Place. | |
|---|---|---|---|---|---|---|
| | | h m s | ° ′ ″ | | s | ″ |
| 62 | L.L. 33895 | 18 17 17·07 | +11 58 26·3 | „ 2, 3 | +0·85 | +10·6 |
| 63 | D.M. +9°, 3885 | 18 44 51·59 | + 9 22 59·7 | „ 2 | +0·96 | +11·9 |
| 64 | W.B. 1186 | 18 48 4·62 | + 9 31 10·0 | Glasgow 3, 4 | +0·96 | +12·2 |
| | | 4·72 | 9·7 | Armagh, 7 | | |
| 65 | L.L. 35624 | 18 58 2·62 | + 8 7 39·0 | Harrow 3 | +1·03 | +12·4 |
| | | 2·53 | 40·3 | Glasgow 2, 3 | | |
| 66 | W.B. 1474 | 18 59 0·71 | + 8 7 39·7 | Harrow 3 | +1·03 | +12·5 |
| 67 | Lamont 4063 | 19 11 6·04 | + 6 43 19·2 | „ 2 | +1·09 | +12·9 |
| 68 | W.B. 405 | 19 26 0·11 | + 4 46 52·2 | „ 4 | +1·17 | +13·2 |
| 69 | D.M. +4°, 4168 | 19 31 40·61 | + 4 24 11·4 | „ 3 | +1·17 | +13·4 |
| | | | 1887·0. | | | |
| 70 | W.B. 1286 | 19 53 0·23 | + 1 21 45·3 | Glasgow 2, 3 | −1·75 | + 4·1 |
| 71 | L.L. 29697 | 16 12 44·19 | − 8 47 36·0 | Harrow 3 | +2·07 | + 2·7 |
| 72 | W.B. 272 | 16 16 25·26 | − 6 35 49·9 | „ 3 | +2·07 | + 3·4 |
| 73 | S.D. −6°, 4425 | 16 18 19·29 | − 6 27 43·0 | „ 4 | +2·07 | + 3·5 |
| 74 | L.L. 29970 | 16 22 48·50 | − 5 11 40·9 | „ 3 | +2·07 | + 3·9 |
| 75 | L.L. 30118 | 16 28 1·95 | − 3 33 5·9 | „ 5 | +2·07 | + 3·5 |
| 76 | Lamont 5231 | 16 32 42·83 | − 1 50 0·5 | „ 3 | +2·07 | + 5·2 |
| 77 | Anonymous 9·2 mag. | 7 9 2·80 | + 8 55 36·5 | Cambridge 4 | +0·87 | − 9·6 |

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## *Observations of the Planet Sappho made at the Cambridge Observatory with the Northumberland Equatorial and Square-Bar Micrometer.*

(*Communicated by Prof. J. C. Adams.*)

| Greenwich Mean Time 1887. | R.A. | Decl. | Number of Comparisons. | Name of Comparison Star. |
|---|---|---|---|---|
| | h m s | ° ′ ″ | | |
| Jan. 12·42844 | 7 0 35·22 | 8 59 37·46 | 10 | Arg. +8°—1651 |
| | 6 52 33·75 | 9 17 24·50 | | „ +9—1352 |
| „ 20·40714 | 6 52 33·89 | 9 17 27·27 | 8 | „ +9—1353 |
| | 6 52 33·97 | 9 17 26·24 | | „ +9—1396 |
| Jan. 25·42877 | 6 48 10·20 | 9 32 1·94 | 10 | „ +9—1314 |
| „ 26·38245 | 6 47 24·51 | 9 35 4·10 | 10 | „ +9—1314 |
| | 6 47 24·38 | 9 35 2·90 | | „ +9—1330 |
| Jan. 31·36133 | 6 43 49·78 | 9 51 44·70 | 12 | „ +9—1297 |
| Feb. 1·42203 | 6 43 9·62 | 9 55 37·46 | 10 | „ +9—1276 |
| Feb. 2·38874 | 6 42 34·78 | 9 59 6·72 | 10 | „ +9—1276 |

Observations not corrected for Aberration and Parallax.

*Places of some Stars which have been compared with the Planet Sappho at the Cambridge Observatory and elsewhere; deduced from observations with the Cambridge Transit Circle.*

| Arg. | No. | Mag. | Mean R.A. Jan. 1, 1887. | Mean N.P.D. Jan. 1, 1887. | Number of Observations |
|---|---|---|---|---|---|
| | ° | | h m s | ° ′ ″ | |
| Arg. | +9—1276 | 7–5 | 6 39 13·314 | 80 7 5·05 | 5 |
| „ | +9—1297 | 8–5 | 6 43 22·912 | 80 15 1·17 | 5 |
| „ | +9—1314 | 7–7 | 6 45 23·784 | 80 25 38·70 | 5 |
| „ | +9—1330 | 8–9 | 6 48 19·610 | 80 22 25·73 | 5 |
| „ | +9—1352 | 9 | 6 50 56·975 | 80 46 15·67 | 4 |
| „ | +9—1353 | 9 | 6 50 58·533 | 80 50 54·87 | 3 |
| „ | +9—1394 | 7–9 | 6 57 2·624 | 80 48 39·80 | 3 |
| „ | +8—1626 | 9–4 | 6 57 3·940 | 81 3 53·64 | 2 |
| „ B.A.C. | +9—1396 2304 | 6 | 6 57 7·239 | 80 41 54·64 | 5 |
| Arg. | +8—1651 | 8–4 | 7 0 33·209 | 81 6 32·65 | 5 |
| „ | +9—1447 | 8–3 | 7 4 27·586 | 81 1 56·56 | 3 |
| „ | +8—1697 | 8–7 | 7 7 8·651 | 81 15 13·51 | 3 |
| „ | +8—1709 | 9–4 | 7 9 2·798 | 81 4 23·47 | 4 |
| „ | +8—1752 | 9 | 7 17 30·215 | 81 12 19·88 | 3 |
| „ | +9—1541 | 8–9 | 7 19 20·611 | 80 59 32·69 | 3 |
| „ | +9—1569 | 9 | 7 22 54·534 | 80 59 24·45 | 3 |
| „ | +8—1801 | 8–5 | 7 26 38·076 | 81 6 13·69 | 3 |

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## *On the Orbit of Comet II.* 1883. By Lieut.-Gen. J. F. Tennant, R.E., F.R.S.

I recently sent a note to the Secretaries acknowledging that Mr. Bryant had pointed out two mistakes in the comparison of the places of this comet with my Ephemeris. I was, however, on looking over his paper, very doubtful as to the mode in which his normal places were obtained, and have examined and repeated my calculations.

Believing that Mr. Bryant had verified all my reductions, I assumed these, with the corrections he pointed out, to be accurate, and proceeded to interpolate the errors of the Ephemeris so as to get the most probable values at the same dates as before. The errors changed a good deal, and on proceeding to compute a parabolic orbit I found that the following (which is close to Mr. Tebbutt's) represented my new places almost exactly:—

Perihelion Passage, 1883, Dec. $25^{d}\!.30221$.

$$\text{Equinox of Jan. 1, 1884}\begin{cases}\pi = 43^\circ\ 12'\ 24''\!.79 \text{ or } \omega = 138^\circ\ 45'\ 03''\!.29,\\ \Omega = 264\ 27\ 21.50,\\ L = 114\ 59\ 03.71,\end{cases}$$

$$\log. q = 9.4919541.$$

This result was so different from Mr. Bryant's, that, having ascertained that he had not verified all my reductions, I once more repeated them, and finding only one sensible change I proceeded to deduce fresh normal places. These were—

| | | R.A. | Dec. |
|---|---|---|---|
| For 1884, Jan. | 17·0 | 340° 41′ 23″·07 ± 2″·31 | −41° 32′ 52″·64 ± 1″·10, |
| | 23·5 | 349 09 20·11 ± 1·98 | −41 58 18·51 ± 2·34, |
| | 30·0 | 355 01 27·03 ± 3·63 | −41 51 55·78 ± 0·88. |

*Longitude.*

| | | | |
|---|---|---|---|
| or for 1884, Jan. | 17·0 | 325° 11′ 34″·2 ± 1″·89 | −30° 39′ 36″·5 ± 1″·24, |
| | 23·5 | 331 36 34·5 ± 2·05 | −33 55 15·3 ± 2·18, |
| | 30·0 | 336 21 03·6 ± 1·83 | −35 54 41·2 ± 2·31, |

all being referred to the equinox of Jan. 1, 1884.

The corresponding places, computed from the elements I have given above, are:—

| | | | |
|---|---|---|---|
| For 1884, Jan. | 17·0 | 325° 11′ 35″·1 | −30° 39′ 36″·6, |
| | 23·5 | 331 36 33·2 | −33 55 14·1, |
| | 30·0 | 336 21 03·9 | −35 54 41·5; |

that is, the elements represent the normal places far within their probable errors. It would seem, then, that the difference of the results at which Mr. Bryant and I have finally arrived is due to the modes in which we have respectively deduced our normal places from observation.

## *Ephemerides of the Satellites of Saturn*, 1887–88. By A. Marth.

In the following ephemerides the five inner satellites are assumed to move in circular orbits in the plane of the ring, the ascending node N and inclination J of which, in reference to the plane of the Earth's equator, are assumed to be

For 1888·0 $N = 126^\circ{\cdot}6279$ $J = 6^\circ{\cdot}9930$.

In the tables P denotes the position-angle of the minor axis of the ring, $L + 180^\circ$ the planetocentric longitude of the Earth referred to the plane of the ring, $\Lambda + 180^\circ$ that of the Sun, or $\Lambda - L$ the difference between the two. The apparent equatorial diameter of the ball and the diameter of the outer rim of the ring depend still on Bessel's determinations. The assumed proportion of the polar axis of the ball to the equatorial diameter is 0·900.

In the tables for the five satellites $a$ and $b$ are the semi-axes of the apparent orbits, $l$–L the longitudes of the satellites in their orbits reckoned from the points which are in superior conjunction with the planet's centre or in opposition to the Earth in longitude. By adding to $l - L$ the value of L from the first table, the longitudes $l$ are found. These longitudes, which are the orbital longitudes from the ascending node added to the right ascension N of the ascending node, reckoned from the point of the true equinox, are corrected for the equation of light, and depend on the following assumed values, which refer to the time when the light arrives at the distance [0·950]:—

| Greenwich Noon. | Mimas. $l_1$ | Enceladus. $l_2$ | Tethys. $l_3$ | Dione. $l_4$ | Rhea. $l_5$ |
|---|---|---|---|---|---|
| 1887, Oct. 15 | 218°950 | 190°745 | 156°156 | 340°497 | 0°883 |
| Nov. 14 | 158·743 | 152·699 | 117·100 | 326·547 | 231·586 |
| Dec. 14 | 98·538 | 114·653 | 78·045 | 312·597 | 102·289 |
| 1888, Jan. 13 | 38·334 | 76·607 | 38·989 | 298·647 | 332·992 |
| Feb. 12 | 338·131 | 38·561 | 359·934 | 284·697 | 203·695 |
| Mar. 13 | 277·989 | 0·515 | 320·878 | 270·747 | 74·398 |
| Apr. 12 | 217·728 | 322·468 | 281·822 | 256·796 | 305·100 |
| May 12 | 157·528 | 284·422 | 242·767 | 242·846 | 175·803 |

The values of P, $a$, $b$ and $l - L$ are to be interpolated directly for the times for which the apparent positions of the satellites are required, and the rectangular co-ordinates $x$ and $y$, reckoned parallel to the axes of the ring, and expressed in seconds of arc, or, if polar co-ordinates are wanted, the position-angles $p$ and distances $s$ of the satellites in reference to the planet's centre, are then found by means of the formulæ:

$$s \sin (p - P) = x = a \sin (l - L),$$
$$s \cos (p - P) = y = b \cos (l - L).$$

| Greenwich Noon. | P | L | Latitude of Earth above plane of Ring. | Latitude of Sun above plane of Ring. | A−L | log $\nu$* |
|---|---|---|---|---|---|---|
| 1887 | ° | ° | ° | ° | ° | |
| Oct. 15 | 352·607 | 130·363 | −18·869 | −21·024 | −6·099 | 9·983285 |
| 20 | ·612 | 130·640 | 18·776 | 20·970 | 6·187 | ·987105 |
| 25 | ·616 | 130·875 | 18·699 | 20·916 | 6·234 | 991009 |
| 30 | ·619 | 131·068 | 18·638 | 20·861 | 6·238 | ·994972 |
| Nov. 4 | 352·622 | 131·218 | −18·593 | −20·806 | −6·199 | 9·998969 |
| 9 | ·624 | 131·323 | 18·565 | 20·751 | 6·116 | 0·002971 |
| 14 | ·625 | 131·383 | 18·554 | 20·696 | 5·988 | ·006949 |
| 19 | ·625 | 131·397 | 18·562 | 20·641 | 5·814 | ·010869 |
| 24 | ·623 | 131·365 | 18·587 | 20·585 | 5·593 | ·014694 |
| 29 | ·621 | 131·287 | 18·629 | 20·530 | 5·327 | ·018391 |
| Dec. 4 | 352·618 | 131·164 | −18·688 | −20·474 | −5·017 | 0·021924 |
| 9 | ·614 | 130·998 | 18·763 | 20·418 | 4·664 | ·025260 |
| 14 | ·609 | 130·791 | 18·854 | 20·361 | 4·269 | ·028362 |
| 19 | ·604 | 130·545 | 18·959 | 20·305 | 3·835 | ·031193 |
| 24 | ·598 | 130·262 | 19·077 | 20·248 | 3·365 | ·033720 |
| 29 | ·591 | 129·947 | 19·206 | 20·191 | 2·863 | ·035914 |
| 1888 | | | | | | |
| Jan. 3 | 352·584 | 129·605 | −19·344 | −20·134 | −2·335 | 0·037749 |
| 8 | ·577 | 129·239 | 19·489 | 20·077 | 1·783 | ·039204 |
| 13 | ·571 | 128·855 | 19·640 | 20·020 | 1·212 | ·040256 |
| 18 | ·564 | 128·458 | 19·794 | 19·962 | 0·629 | ·040891 |
| 23 | ·558 | 128·054 | 19·948 | 19·904 | −0·039 | ·041101 |
| 28 | ·552 | 127·649 | 20·102 | 19·846 | +0·552 | ·040886 |
| Feb. 2 | 352·546 | 127·249 | −20·252 | −19·788 | +1·137 | 0·040250 |
| 7 | ·541 | 126·859 | 20·396 | 19·730 | 1·712 | ·039201 |

* Log $\nu = 0·950 - \log \Delta$, the *Naut. Alm.* values of the distances $\Delta$ being altered to take the equation of light into account.—In deducing from the measurements of the satellites' positions the dimensions of their orbits, and consequently the mass of *Saturn*, the effect of the existing uncertainty concerning the correctness of the planet's tabular distances from the Sun and from the Earth must not be lost sight of. The difference between the distances derived from Bouvard's and from Le Verrier's tables of *Saturn* for the opposition of 1879 (the only one, so far as I know, for which computations from both tables are available) corresponds to a difference of about 3 units in the deduced proportion of the mass of the Sun to that of *Saturn*, and in the next preceding oppositions the difference has probably been larger. As the observed positions of the planet show that in 1879 Le Verrier's tables give the heliocentric longitudes of *Saturn* about 12″·7 too great, while Bouvard's give them about 8″·9 too small, the differences of the tabular values of the radius vector raise a question at present beset with doubt. If heliocentric places of *Saturn*, computed accurately from Le Verrier's tables for the years preceding 1879, exist anywhere, the publication of at least part of them, be it even of only one place for each opposition, would be of service and would be appreciated.

| Greenwich Noon. | P | L | Latitude of Earth above plane of Ring. | Latitude of Sun above plane of Ring. | Δ−L | log $r^2$ |
|---|---|---|---|---|---|---|
| 1888 | ° | ° | ° | ° | ° | |
| Feb. 12 | ·537 | 126·485 | 20·534 | 19·671 | 2·271 | ·037751 |
| 17 | ·533 | 126·133 | 20·662 | 19·613 | 2·808 | ·035918 |
| 22 | ·530 | 125·808 | 20·780 | 19·554 | 3·318 | ·033728 |
| 27 | ·527 | 125·514 | 20·886 | 19·495 | 3·797 | ·031208 |
| Mar. 3 | 352·525 | 125·255 | −20·979 | −19·435 | +4·241 | 0·028389 |
| 8 | ·523 | 125·034 | 21·058 | 19·376 | 4·646 | ·025301 |
| 13 | ·522 | 124·854 | 21·122 | 19·316 | 5·010 | ·021977 |
| 18 | ·521 | 124·717 | 21·172 | 19·257 | 5·331 | ·018452 |
| 23 | ·520 | 124·625 | 21·206 | 19·197 | 5·607 | ·014764 |
| 28 | ·520 | 124·579 | 21·225 | 19·137 | 5·837 | ·010947 |
| Apr. 2 | 352·520 | 124·579 | −21·228 | −19·076 | +6·021 | 0·007034 |
| 7 | ·520 | 124·625 | 21·216 | 19·016 | 6·158 | 0·003056 |
| 12 | ·521 | 124·716 | 21·188 | 18·955 | 6·250 | 9·999044 |
| 17 | ·521 | 124·853 | 21·145 | 18·894 | 6·295 | ·995030 |
| 22 | ·522 | 125·034 | 21·087 | 18·833 | 6·297 | ·991043 |
| 27 | ·524 | 125·257 | 21·015 | 18·772 | 6·257 | ·987108 |
| May 2 | 352·526 | 125·521 | −20·929 | −18·711 | +6·175 | 9·983248 |
| 7 | ·528 | 125·824 | 20·829 | 18·649 | 6·054 | ·979484 |
| 12 | 352·531 | 126·164 | −20·715 | −18·588 | +5·879 | 9·975837 |

| Greenwich Noon. | Diameter of Ball. Equat. | Phase prec. l. | Polar | Axis of Ring. Major | Minor | *Mimas.* $a_1$ | $b_1$ | $l_1-L$ | |
|---|---|---|---|---|---|---|---|---|---|
| 1887. | ″ | ″ | ″ | ″ | ″ | ″ | ″ | ° | ° |
| Oct. 15 | 17·57 | 0·050 | 16·00 | 40·50 | 13·10 | 27·67 | − 8·95 | 87·82 | 1909·87 |
| 20 | 17·72 | ·052 | 16·14 | 40·86 | 13·15 | 27·91 | 8·99 | 197·69 | ·91 |
| 25 | 17·88 | ·053 | 16·29 | 41·23 | 13·22 | 28·17 | 9·03 | 307·60 | 1909·95 |
| 30 | 18·05 | ·053 | 16·44 | 41·60 | 13·30 | 28·43 | 9·08 | 57·55 | 1910·00 |
| Nov. 4 | 18·21 | ·053 | 16·59 | 41·99 | 13·39 | 28·69 | − 9·15 | 167·55 | ·04 |
| 9 | 18·38 | ·052 | 16·74 | 42·38 | 13·49 | 28·95 | 9·22 | 277·59 | ·08 |
| 14 | 18·55 | ·051 | 16·89 | 42·77 | 13·61 | 29·22 | 9·30 | 27·67 | ·12 |
| 19 | 18·72 | ·048 | 17·05 | 43·16 | 13·74 | 29·49 | 9·39 | 137·79 | ·17 |
| 24 | 18·89 | ·045 | 17·20 | 43·54 | 13·88 | 29·75 | 9·48 | 247·96 | ·21 |
| 29 | 19·05 | ·041 | 17·35 | 43·91 | 14·03 | 30·00 | 9·58 | 358·17 | ·24 |
| Dec. 4 | 19·20 | ·037 | 17·49 | 44·27 | 14·18 | 30·24 | − 9·69 | 108·41 | 1910·27 |
| 9 | 19·35 | ·032 | 17·63 | 44·61 | 14·35 | 30·48 | 9·80 | 218·68 | ·31 |
| 14 | 19·49 | ·027 | 17·75 | 44·93 | 14·52 | 30·70 | 9·92 | 328·99 | ·33 |
| 19 | 19·62 | ·022 | 17·87 | 45·23 | 14·69 | 30·90 | 10·04 | 79·32 | ·35 |
| 24 | 19·73 | ·017 | 17·98 | 45·49 | 14·87 | 31·08 | 10·16 | 189·67 | ·37 |
| 29 | 19·83 | ·012 | 18·07 | 45·72 | 15·04 | 31·24 | 10·28 | 300·04 | ·39 |

| Greenwich Noon. | Diameter of Ball. Equat. | Phase prec. l. | Polar | Axis of Ring. Major | Minor | *Mimas.* $a_1$ | $b_1$ | $l_1-L$ | |
|---|---|---|---|---|---|---|---|---|---|
| 1888. | " | " | " | " | " | " | " | ° | ° |
| Jan. 3 | 19·92 | 0·008 | 18·15 | 45·91 | 15·21 | 31·37 | −10·39 | 50·43 | 1910·39 |
| 8 | 19·98 | ·005 | 18·22 | 46·06 | 15·37 | 31·47 | 10·50 | 160·82 | ·40 |
| 13 | 20·03 | ·002 | 18·27 | 46·18 | 15·52 | 31·55 | 10·60 | 271·22 | ·39 |
| 18 | 20·06 | ·001 | 18·30 | 46·24 | 15·66 | 31·59 | 10·70 | 21·61 | ·38 |
| 23 | 20·07 | foll. | 18·31 | 46·27 | 15·78 | 31·61 | 10·78 | 131·99 | ·36 |
| 28 | 20·06 | limb. | 18·30 | 46·24 | 15·89 | 31·59 | 10·86 | 242·35 | ·34 |
| Feb. 2 | 20·03 | ·002 | 18·28 | 46·18 | 15·98 | 31·55 | −10·92 | 352·69 | 1910·31 |
| 7 | 19·98 | ·005 | 18·24 | 46·06 | 16·05 | 31·47 | 10·97 | 103·00 | ·28 |
| 12 | 19·92 | ·008 | 18·18 | 45·91 | 16·10 | 31·37 | 11·00 | 213·28 | ·24 |
| 17 | 19·83 | ·012 | 18·11 | 45·72 | 16·13 | 31·24 | 11·02 | 323·52 | ·20 |
| 22 | 19·73 | ·017 | 18·02 | 45·49 | 16·14 | 31·08 | 11·03 | 73·72 | ·15 |
| 27 | 19·62 | ·022 | 17·92 | 45·22 | 16·12 | 30·90 | 11·02 | 183·87 | ·11 |
| Mar. 3 | 19·49 | ·027 | 17·80 | 44·93 | 16·09 | 30·70 | −10·99 | 293·98 | ·06 |
| 8 | 19·35 | ·032 | 17·68 | 44·61 | 16·03 | 30·48 | 10·95 | 44·04 | 1910·00 |
| 13 | 19·21 | ·037 | 17·55 | 44·27 | 15·95 | 30·25 | 10·90 | 154·04 | 1909·95 |
| 18 | 19·05 | ·041 | 17·41 | 43·91 | 15·86 | 30·00 | 10·84 | 263·99 | ·90 |
| 23 | 18·89 | ·045 | 17·26 | 43·54 | 15·75 | 29·75 | 10·76 | 13·89 | ·85 |
| 28 | 18·72 | ·048 | 17·11 | 43·16 | 15·63 | 29·49 | 10·68 | 123·74 | ·79 |
| Apr. 2 | 18·56 | ·051 | 16·96 | 42·78 | 15·49 | 29·23 | −10·58 | 233·53 | ·74 |
| 7 | 18·39 | ·053 | 16·80 | 42·39 | 15·34 | 28·96 | 10·48 | 343·27 | ·70 |
| 12 | 18·22 | ·054 | 16·65 | 42·00 | 15·18 | 28·69 | 10·37 | 92·97 | ·65 |
| 17 | 18·05 | ·054 | 16·49 | 41·61 | 15·01 | 28·43 | 10·26 | 202·62 | ·60 |
| 22 | 17·88 | ·054 | 16·34 | 41·23 | 14·83 | 28·17 | 10·13 | 312·22 | ·56 |
| 27 | 17·72 | ·053 | 16·19 | 40·86 | 14·65 | 27·92 | 10·01 | 61·78 | ·52 |
| May 2 | 17·57 | ·051 | 16·04 | 40·50 | 14·46 | 27·67 | − 9·88 | 171·30 | ·49 |
| 7 | 17·42 | ·049 | 15·90 | 40·15 | 14·27 | 27·43 | 9·75 | 280·79 | 1909·45 |
| 12 | 17·27 | 0·046 | 15·77 | 39·81 | 14·08 | 27·20 | 9·62 | 30·24 | |

| Greenwich Noon. | *Enceladus.* $a_2$ | $b_2$ | $l_2-L$ | Diff. | *Tethys.* $a_3$ | $b_3$ | $l_3-L$ | Diff. |
|---|---|---|---|---|---|---|---|---|
| 1887. | " | " | ° | ° | " | " | ° | ° |
| Oct. 15 | 35·50 | −11·48 | 59·85 | 1313·51 | 43·94 | −14·21 | 25·41 | 953·30 |
| 20 | 35·81 | 11·53 | 293·36 | ·55 | 44·33 | 14·27 | 258·71 | ·35 |
| 25 | 36·13 | 11·58 | 166·91 | ·59 | 44·73 | 14·34 | 132·06 | ·39 |
| 30 | 36·46 | 11·65 | 40·50 | ·63 | 45·14 | 14·43 | 5·45 | ·43 |
| Nov. 4 | 36·80 | −11·73 | 274·13 | 1313·68 | 45·56 | −14·53 | 238·88 | 953·47 |
| 9 | 37·14 | 11·83 | 147·81 | ·72 | 45·98 | 14·64 | 112·35 | ·52 |
| 14 | 37·48 | 11·93 | 21·53 | ·76 | 46·40 | 14·77 | 345·87 | ·56 |
| 19 | 37·82 | 12·04 | 255·29 | ·81 | 46·82 | 14·90 | 210·43 | 61 |

| Greenwich Noon. | *Enceladus.* $a_2$ | $b_2$ | $l_2-L$ | Diff. | *Tethys.* $a_3$ | $b_3$ | $l_3-L$ | Diff. |
|---|---|---|---|---|---|---|---|---|
| 1887. | ″ | ″ | ° | ° | ″ | ″ | ° | ° |
| Nov. 24 | 38·16 | 12·16 | 129·10 | ·85 | 47·24 | 15·06 | 93·04 | ·69 |
| 29 | 38·49 | 12·29 | 2·95 | ·88 | 47·64 | 15·22 | 326·69 | ·65 |
| Dec. 4 | 38·80 | −12·43 | 236·83 | 1313·92 | 48·03 | −15·39 | 200·38 | 953·73 |
| 9 | 39·10 | 12·58 | 110·75 | ·96 | 48·40 | 15·57 | 74·11 | ·76 |
| 14 | 39·38 | 12·73 | 344·71 | 1313·99 | 48·75 | 15·75 | 307·87 | ·80 |
| 19 | 39·64 | 12·88 | 218·70 | 1314·02 | 49·07 | 15·94 | 181·67 | ·83 |
| 24 | 39·87 | 13·03 | 92·72 | ·04 | 49·35 | 16·13 | 55·50 | ·85 |
| 29 | 40·07 | 13·18 | 326·76 | ·05 | 49·60 | 16·32 | 289·35 | ·87 |
| 1888. | | | | | | | | |
| Jan. 3 | 40·24 | −13·33 | 200·81 | 1314·07 | 49·81 | −16·50 | 163·22 | 953·89 |
| 8 | 40·37 | 13·47 | 74·88 | ·07 | 49·98 | 16·67 | 37·11 | ·89 |
| 13 | 40·47 | 13·60 | 308·95 | ·07 | 50·10 | 16·84 | 271·00 | ·90 |
| 18 | 40·53 | 13·73 | 183·02 | ·07 | 50·17 | 16·99 | 144·90 | ·90 |
| 23 | 40·55 | 13·84 | 57·09 | ·06 | 50·20 | 17·13 | 18·80 | ·89 |
| 28 | 40·53 | 13·93 | 291·15 | ·04 | 50·17 | 17·24 | 252·69 | ·88 |
| Feb. 2 | 40·47 | −14·01 | 165·19 | 1314·02 | 50·10 | −17·34 | 126·57 | 953·86 |
| 7 | 40·37 | 14·07 | 39·21 | 1313·99 | 49·98 | 17·42 | 0·43 | ·83 |
| 12 | 40·24 | 14·11 | 273·20 | ·96 | 49·81 | 17·47 | 234·26 | ·81 |
| 17 | 40·07 | 14·14 | 147·16 | ·92 | 49·60 | 17·50 | 108·07 | ·77 |
| 22 | 39·87 | 14·14 | 21·08 | ·88 | 49·35 | 17·51 | 341·84 | ·73 |
| 27 | 39·64 | 14·13 | 254·96 | ·84 | 49·07 | 17·49 | 215·57 | ·69 |
| Mar. 3 | 39·38 | −14·10 | 128·80 | 1313·79 | 48·75 | −17·45 | 89·26 | 953·65 |
| 8 | 39·10 | 14·05 | 2·59 | ·74 | 48·41 | 17·39 | 322·91 | ·60 |
| 13 | 38·81 | 13·98 | 236·33 | ·69 | 48·04 | 17·31 | 196·51 | ·55 |
| 18 | 38·49 | 13·90 | 110·02 | ·64 | 47·65 | 17·21 | 70·06 | ·50 |
| 23 | 38·17 | 13·81 | 343·66 | ·59 | 47·25 | 17·09 | 303·56 | ·45 |
| 28 | 37·83 | 13·70 | 217·25 | ·54 | 46·83 | 16·95 | 177·01 | ·41 |
| Apr. 2 | 37·49 | −13·58 | 90·79 | 1313·49 | 46·41 | −16·80 | 50·42 | 953·35 |
| 7 | 37·15 | 13·44 | 324·28 | ·44 | 45·99 | 16·64 | 283·77 | ·31 |
| 12 | 36·81 | 13·30 | 197·72 | ·40 | 45·57 | 16·47 | 157·08 | ·27 |
| 17 | 36·47 | 13·16 | 71·12 | ·35 | 45·15 | 16·29 | 30·35 | ·22 |
| 22 | 36·14 | 13·00 | 304·47 | ·31 | 44·73 | 16·09 | 263·57 | ·17 |
| 27 | 35·81 | 12·84 | 177·78 | ·27 | 44·33 | 15·90 | 136·74 | ·14 |
| May 2 | 35·49 | −12·68 | 51·05 | 1313·24 | 43·94 | −15·69 | 9·88 | 953·10 |
| 7 | 35·29 | 12·51 | 284·29 | ·20 | 43·56 | 15·49 | 242·98 | ·06 |
| 12 | 34·89 | 12·34 | 157·49 | | 43·19 | 15·28 | 116·04 | |

| Greenwich Noon. | | *Dione.* $a_4$ | $b_4$ | $l_4$—L | Diff. | *Rhea.* $a_5$ | $b_5$ | $l_5$—L | Diff. |
|---|---|---|---|---|---|---|---|---|---|
| 1887. | | ″ | ″ | ° | ° | ″ | ″ | ° | ° |
| Oct. | 15 | 56·28 | −18·20 | 209·87 | 657·46 | 78·59 | −25·42 | 230·36 | 398·21 |
| | 20 | 56·78 | 18·28 | 147·33 | ·50 | 79·29 | 25·52 | 268·57 | ·25 |
| | 25 | 57·29 | 18·37 | 84·83 | ·54 | 80·00 | 25·65 | 306·82 | ·30 |
| | 30 | 57·81 | 18·48 | 22·37 | ·59 | 80·74 | 25·80 | 345·12 | ·34 |
| Nov. | 4 | 58·35 | −18·60 | 319·96 | 657·63 | 81·48 | −25·98 | 23·46 | 398·38 |
| | 9 | 58·89 | 18·75 | 257·59 | ·68 | 82·24 | 26·18 | 61·84 | ·43 |
| | 14 | 59·43 | 18·91 | 195·27 | ·72 | 82·99 | 26·41 | 100·27 | ·47 |
| | 19 | 59·97 | 19·09 | 132·99 | ·77 | 83·75 | 26·66 | 138·74 | ·52 |
| | 24 | 60·50 | 19·28 | 70·76 | ·81 | 84·49 | 26·93 | 177·26 | ·56 |
| | 29 | 61·02 | 19·49 | 8·57 | ·85 | 85·21 | 27·22 | 215·82 | ·60 |
| Dec. | 4 | 61·51 | −19·71 | 306·42 | ·89 | 85·91 | −27·53 | 254·42 | 398·65 |
| | 9 | 61·99 | 19·94 | 244·31 | ·92 | 86·57 | 27·85 | 293·07 | ·69 |
| | 14 | 62·43 | 20·18 | 182·23 | 657·96 | 87·19 | 28·18 | 331·76 | ·72 |
| | 19 | 62·84 | 20·42 | 120·19 | 658·00 | 87·76 | 28·51 | 10·48 | ·75 |
| | 24 | 63·21 | 20·66 | 58·19 | ·02 | 88·27 | 28·85 | 49·23 | ·79 |
| | 29 | 63·53 | 20·90 | 356·21 | ·04 | 88·72 | 29·18 | 88·02 | ·81 |
| 1888. | | | | | | | | | |
| Jan. | 3 | 63·80 | −21·13 | 294·25 | 658·06 | 89·09 | −29·51 | 126·83 | 398·83 |
| | 8 | 64·01 | 21·36 | 232·31 | ·08 | 89·39 | 29·82 | 165·66 | ·84 |
| | 13 | 64·17 | 21·57 | 170·39 | ·08 | 89·61 | 30·12 | 204·50 | ·85 |
| | 18 | 64·26 | 21·76 | 108·47 | ·08 | 89·74 | 30·39 | 243·35 | ·86 |
| | 23 | 64·29 | 21·93 | 46·55 | ·08 | 89·78 | 30·63 | 282·21 | ·85 |
| | 28 | 64·26 | 22·09 | 344·63 | ·07 | 89·74 | 30·84 | 321·06 | ·85 |
| Feb. | 2 | 64·17 | −22·21 | 282·70 | ·05 | 89·61 | −31·02 | 359·91 | 398·83 |
| | 7 | 64·01 | 22·31 | 220·75 | ·02 | 89·39 | 31·15 | 38·74 | ·81 |
| | 12 | 63·80 | 22·38 | 158·77 | 658 00 | 89·09 | 31·25 | 77·55 | ·79 |
| | 17 | 63·53 | 22·42 | 96·77 | 657·97 | 88·72 | 31·31 | 116·34 | ·75 |
| | 22 | 63·21 | 22·43 | 34·74 | ·94 | 88·27 | 31·32 | 155·09 | ·72 |
| | 27 | 62·84 | 22·40 | 332·68 | ·89 | 87·76 | 31·29 | 193·81 | ·69 |
| Mar. | 3 | 62·44 | −22·35 | 270·57 | ·85 | 87·19 | −31·22 | 232·50 | 398·65 |
| | 8 | 62·00 | 22·28 | 208·42 | ·81 | 86·58 | 31·11 | 271·15 | ·60 |
| | 13 | 61·52 | 22·17 | 146·23 | ·76 | 85·92 | 30·96 | 309·75 | ·55 |
| | 18 | 61·03 | 22·04 | 83·99 | ·71 | 85·22 | 30·78 | 348·30 | ·51 |
| | 23 | 60·51 | 21·89 | 21·70 | ·66 | 84·50 | 30·57 | 26·81 | ·46 |
| | 28 | 59·98 | 21·71 | 319·36 | ·62 | 83·76 | 30·33 | 65·27 | ·42 |
| Apr. | 2 | 59·44 | −21·52 | 256·98 | 657·57 | 83·01 | −30·06 | 103·69 | 398·37 |
| | 7 | 58·90 | 21·32 | 194·55 | ·52 | 82·25 | 29·77 | 142·06 | ·32 |
| | 12 | 58·36 | 21·09 | 132·07 | ·47 | 81·50 | 29·46 | 180·38 | ·27 |

| Greenwich Noon. | *Dione.* $a_4$ | $b_4$ | $l_4$—L | Diff. | *Rhea.* $a_5$ | $b_5$ | $l_5$—L | Diff. |
|---|---|---|---|---|---|---|---|---|
| 1887. | ″ | ″ | ° | ° | ″ | ″ | ° | ° |
| Apr. 17 | 57·82 | 20·86 | 69·54 | ·43 | 80·75 | 29·13 | 218·65 | ·23 |
| 22 | 57·29 | 20·61 | 6·97 | ·39 | 80·01 | 28·79 | 256·88 | ·19 |
| 27 | 56·78 | 20·36 | 304·36 | ·35 | 79·29 | 28·43 | 295·07 | ·15 |
| May 2 | 56·27 | −20·10 | 241·71 | 657·31 | 78·59 | −28·07 | 333·22 | 398·11 |
| 7 | 55·79 | 19·84 | 179·02 | ·28 | 77·91 | 27·70 | 11·33 | ·07 |
| 12 | 55·32 | 19·57 | 116·30 | | 77·26 | 27·33 | 49·40 | |

Approximate Greenwich mean times of conjunctions of the satellites with the centre of the planet or of their passages in the direction of the minor axis of the ring.

"n" inferior conjunction, or satellite north, moving from the following to the preceding side.

"s" superior conjunction, or satellite south, moving from the preceding to the following side.

In the case of *Titan* and *Iapetus* the approximate distances from the centre or from the major axis of the ring are added, at which they pass in the direction of the minor axis.

| 1887 | h | |
|---|---|---|
| Nov. 1 | 10·7 | Rh. n. |
| | 13·6 | Di. s. |
| | 14·1 | En. s. |
| | 16·2 | Mi. s. |
| | 19·3 | Te. n. |
| 2 | 14·9 | Mi. s. |
| | 17·9 | Te. s. |
| | 22·5 | Di. n. |
| | 23·0 | En. s. |
| 3 | 13·5 | Mi. s. |
| | 15·4 | En. n. |
| | 16·6 | Te. n. |
| | 16·9 | Rh. s. |
| 4 | 7·3 | Di. s. |
| | 7·8 | En. s. |
| | 12·1 | Mi. s. |
| | 15·2 | Te. s. |
| 5 | 1·0 | Tit. s. 61″ |
| | 13·9 | Te. n. |
| | 16·2 | Di. n. |
| | 16·7 | En. s. |
| | 23·1 | Rh. n. |
| 6 | 12·5 | Te. s. |
| 7 | 1·0 | Di. s. |
| | 11·2 | Te. n. |
| 8 | 5·4 | Rh. s. |
| | 9·8 | Di. n. |
| | 9·9 | Te. s. |
| | 10·5 | En. s. |
| 9 | 8·5 | Te. n. |
| | 16·5 | Mi. n. |
| | 18·7 | Di. s. |
| | 19·4 | En. s. |

| | h | |
|---|---|---|
| Nov. 10 | 7·2 | Te. s. |
| | 11·6 | Rh. n. |
| | 11·8 | En. n. |
| | 15·1 | Mi. n. |
| 11 | 3·5 | Di. n. |
| | 5·8 | Te. n. |
| | 13·7 | Mi. n. |
| | 20·7 | En. n. |
| 12 | 4·5 | Te. s. |
| | 12·3 | Mi. n. |
| | 12·4 | Di. s. |
| | 13·1 | En. s. |
| | 17·8 | Rh. s. |
| | 20·2 | Tit. n. 58″ |
| 13 | 3·1 | Te. n. |
| | 10·9 | Mi. n. |
| | 21·2 | Di. n. |
| | 22·0 | En. s. |
| 14 | 1·8 | Te. s. |
| | 8·7 | Iap. s. 52″ |
| | 14·5 | En. n. |
| | 20·9 | Mi. s. |
| 15 | 0·0 | Rh. n. |
| | 0·4 | Te. n. |
| | 6·1 | Di. s. |
| | 6·9 | En. s. |
| | 19·5 | Mi. s. |
| | 23·1 | Te. s. |
| 16 | 14·9 | Di. n. |
| | 15·8 | En. s. |
| | 18·1 | Mi. s. |
| | 21·7 | Te. n. |
| 17 | 6·2 | Rh. s. |

| | h | |
|---|---|---|
| Nov. 17 | 8·2 | En. n. |
| | 16·7 | Mi. s. |
| | 20·4 | Te. s. |
| | 23·7 | Di. s. |
| 18 | 15·3 | Mi. s. |
| | 17·1 | En. n. |
| | 19·0 | Te. n. |
| 19 | 8·6 | Di. n. |
| | 9·6 | En. s. |
| | 12·4 | Rh. n. |
| | 14·0 | Mi. s. |
| | 17·7 | Te. s. |
| 20 | 12·6 | Mi. s. |
| | 16·3 | Te. n. |
| | 17·4 | Di. s. |
| | 18·4 | En. s. |
| | 23·8 | Tit. s. 62″ |
| 21 | 10·9 | En. n. |
| | 11·2 | Mi. s. |
| | 15·0 | Te. s. |
| | 18·6 | Rh. s. |
| 22 | 2·2 | Di. n. |
| | 13·6 | Te. n. |
| | 19·8 | En. n. |
| | 21·1 | Mi. n. |
| 23 | 11·1 | Di. s. |
| | 12·2 | En. s. |
| | 12·3 | Te. s. |
| | 19·7 | Mi. n. |
| 24 | 0·8 | Rh. n. |
| | 10·9 | Te. n. |
| | 18·3 | Mi. n. |
| | 19·9 | Di. n. |

| 1887 | h | | |
|---|---|---|---|
| Nov. 24 | 21·1 | En. s. | |
| 25 | 9·6 | Te. s. | |
| | 13·5 | En. n. | |
| | 17·0 | Mi. n. | |
| 26 | 4·8 | Di. s. | |
| | 7·0 | Rh. s. | |
| | 8·2 | Te. n. | |
| | 15·6 | Mi. n. | |
| | 22·4 | En. n. | |
| 27 | 6·9 | Te. s. | |
| | 13·6 | Di. n. | |
| | 14·2 | Mi. n. | |
| | 14·8 | En. s. | |
| 28 | 5·5 | Te. n. | |
| | 7·3 | En. n. | |
| | 12·8 | Mi. n. | |
| | 13·2 | Rh. n. | |
| | 18·7 | Tit. n. | 60″ |
| | 22·4 | Di. s. | |
| 29 | 4·2 | Te. s. | |
| | 11·4 | Mi. n. | |
| | 16·2 | En. n. | |
| | 22·7 | Mi. s. | |
| 30 | 2·8 | Te. n. | |
| | 7·3 | Di. n. | |
| | 8·6 | En. s. | |
| | 10·0 | Mi. n. | |
| | 19·4 | Rh. s. | |
| Dec. 1 | 1·5 | Te. s. | |
| | 16·1 | Di. s. | |
| | 17·5 | En. s. | |
| | 20·0 | Mi. s. | |
| 2 | 0·1 | Te. n. | |
| | 9·9 | En. n. | |
| | 18·6 | Mi. s. | |
| | 22·8 | Te. s. | |
| 3 | 0·9 | Di. n. | |
| | 1·6 | Rh. n. | |
| | 17·2 | Mi. s. | |
| | 18·8 | En. n. | |
| | 21·4 | Te. n. | |
| 4 | 9·8 | Di. s. | |
| | 11·2 | En. s. | |
| | 15·8 | Mi. s. | |
| | 20·1 | Te. s. | |
| 5 | 7·8 | Rh. s. | |
| | 14·4 | Mi. s. | |
| | 18·6 | Di. n. | |
| | 18·7 | Te. n. | |
| | 20·1 | En. s. | |
| 6 | 12·6 | En. n. | |
| | 13·0 | Mi. s. | |
| | 17·4 | Te. s. | |
| | 22·0 | Tit. s. | 64″ |
| 7 | 3·4 | Di. s. | |
| | 11·6 | Mi. s. | |
| | 14·0 | Rh. n. | |
| | 16·0 | Te. n. | |
| | 21·4 | En. n. | |

| | h | | |
|---|---|---|---|
| Dec. 8 | 10·3 | Mi. s. | |
| | 12·3 | Di. n. | |
| | 13·9 | En. s. | |
| | 14·7 | Te. s. | |
| 9 | 13·3 | Te. n. | |
| | 20·1 | Rh. s. | |
| | 20·2 | Mi. n. | |
| | 21·1 | Di. s. | |
| | 22·8 | En. s. | |
| 10 | 12·0 | Te. s. | |
| | 15·2 | En. n. | |
| | 18·8 | Mi. n. | |
| 11 | 5·9 | Di. n. | |
| | 7·6 | En. s. | |
| | 10·6 | Te. n. | |
| | 17·4 | Mi. n. | |
| 12 | 2·3 | Rh. n. | |
| | 9·3 | Te. s. | |
| | 14·8 | Di. s. | |
| | 16·0 | Mi. n. | |
| | 16·5 | En. s. | |
| 13 | 7·9 | Te. n. | |
| | 9·0 | En. n. | |
| | 14·6 | Mi. n. | |
| | 23·6 | Di. n. | |
| 14 | 6·6 | Te. s. | |
| | 8·5 | Rh. s. | |
| | 13·3 | Mi. n. | |
| | 16·9 | Tit. n. | 62″ |
| | 17·8 | En. n. | |
| 15 | 5·2 | Te. n. | |
| | 8·4 | Di. s. | |
| | 10·3 | En. s. | |
| | 11·9 | Mi. n. | |
| 16 | 3·8 | Te. s. | |
| | 10·5 | Mi. n. | |
| | 14·7 | Rh. n. | |
| | 17·2 | Di. n. | |
| | 19·1 | En. s. | |
| 17 | 2·5 | Te. n. | |
| | 11·6 | En. n. | |
| | 20·4 | Mi. s. | |
| 18 | 1·1 | Te. s. | |
| | 2·1 | Di. s. | |
| | 19·0 | Mi. s. | |
| | 20·5 | En. n. | |
| | 20·8 | Rh. s. | |
| | 23·8 | Te. n. | |
| 19 | 10·9 | Di. n. | |
| | 12·9 | En. s. | |
| | 17·6 | Mi. s. | |
| | 22·4 | Te. s. | |
| 20 | 16·2 | Mi. s. | |
| | 19·7 | Di. s. | |
| | 21·1 | Te. n. | |
| | 21·8 | En. s. | |
| 21 | 3·0 | Rh. n. | |
| | 14·2 | En. n. | |
| | 14·9 | Mi. s. | |

| | h | | |
|---|---|---|---|
| Dec. 21 | 19·7 | Te. s. | |
| 22 | 4·6 | Di. n. | |
| | 6·7 | En. s. | |
| | 13·5 | Mi. s. | |
| | 18·4 | Te. n. | |
| | 20·0 | Tit. s. | 66″ |
| 23 | 9·2 | Rh. s. | |
| | 12·1 | Mi. s. | |
| | 13·4 | Di. s. | |
| | 15·5 | En. s. | |
| | 17·0 | Te. s. | |
| 24 | 8·0 | En. n. | |
| | 10·7 | Mi. s. | |
| | 15·7 | Te. n. | |
| | 19·5 | Iap. n. | 58″ |
| | 22·2 | Di. n. | |
| 25 | 14·3 | Te. s. | |
| | 15·3 | Rh. n. | |
| | 16·8 | En. n. | |
| | 20·6 | Mi. n. | |
| 26 | 7·0 | Di. s. | |
| | 9·3 | En. s. | |
| | 12·9 | Te. n. | |
| | 19·2 | Mi. n. | |
| 27 | 11·6 | Te. s. | |
| | 15·9 | Di. n. | |
| | 17·8 | Mi. n. | |
| | 18·2 | En. s. | |
| | 21·5 | Rh. s. | |
| 28 | 10·2 | Te. n. | |
| | 10·6 | En. n. | |
| | 16·5 | Mi. n. | |
| 29 | 0·7 | Di. s. | |
| | 8·9 | Te. s. | |
| | 15·1 | Mi. n. | |
| | 19·5 | En. n. | |
| 30 | 3·7 | Rh. n. | |
| | 7·5 | Te. n. | |
| | 9·5 | Di. n. | |
| | 11·9 | En. s. | |
| | 13·7 | Mi. n. | |
| | 14·8 | Tit. n. | 64″ |
| 31 | 6·2 | Te. s. | |
| | 12·3 | Mi. n. | |
| | 18·3 | Di. s. | |
| | 20·8 | En. s. | |
| 1888 | h | | |
| Jan. 1 | 4·8 | Te. n. | |
| | 9·8 | Rh. s. | |
| | 10·9 | Mi. n. | |
| | 13·2 | En. n. | |
| 2 | 3·2 | Di. n. | |
| | 3·5 | Te. s. | |
| | 20·8 | Mi. s. | |
| | 22·1 | En. n. | |
| 3 | 2·1 | Te. n. | |
| | 12·0 | Di. s. | |
| | 14·5 | En. s. | |
| | 16·0 | Rh. n. | |

| 1888 | h | |
|---|---|---|
| Jan. 3 | 19·4 | Mi. s. |
| 4 | 0·8 | Te. s. |
| | 7·0 | En. n. |
| | 18·1 | Mi. s. |
| | 20·8 | Di. n. |
| | 23·4 | Te. n. |
| 5 | 15·8 | En. n. |
| | 16·7 | Mi. s. |
| | 22·0 | Te. s. |
| | 22·1 | Rh. s. |
| 6 | 5·6 | Di. s. |
| | 8·3 | En. s. |
| | 15·3 | Mi. s. |
| | 20·7 | Te. n. |
| 7 | 13·9 | Mi. s. |
| | 14·5 | Di. n. |
| | 17·2 | En. s. |
| | 17·4 | Tit. s. 68″ |
| | 19·3 | Te. s. |
| 8 | 4·3 | Rh. n. |
| | 9·6 | En. n. |
| | 12·5 | Mi. s. |
| | 18·0 | Te. n. |
| | 23·3 | Di. s. |
| 9 | 11·1 | Mi. s. |
| | 16·6 | Te. s. |
| | 18·5 | En. n. |
| 10 | 8·1 | Di. n. |
| | 9·7 | Mi. s. |
| | 10·5 | Rh. s. |
| | 10·9 | En. s. |
| | 15·3 | Te. n. |
| 11 | 13·9 | Te. s. |
| | 16·9 | Di. s. |
| | 19·7 | Mi. n. |
| | 19·8 | En. s. |
| 12 | 12·2 | En. n. |
| | 12·5 | Te. n. |
| | 16·6 | Rh. n. |
| | 18·3 | Mi. n. |
| 13 | 1·7 | Di. n. |
| | 11·2 | Te. s. |
| | 16·9 | Mi. n. |
| | 21·1 | En. n. |
| 14 | 9·8 | Te. n. |
| | 10·6 | Di. s. |
| | 13·5 | En. s. |
| | 15·5 | Mi. n. |
| | 22·8 | Rh. s. |
| 15 | 6·0 | En. n. |
| | 8·5 | Te. s. |
| | 12·1 | Tit. n. 66″ |
| | 14·1 | Mi. n. |
| | 19·4 | Di. n. |
| 16 | 7·1 | Te. n. |
| | 12·7 | Mi. n. |
| | 14·8 | En. n. |
| 17 | 4·2 | Di. s. |
| | 4·9 | Rh. n. |
| Jan. 17 | 5·8 | Te. s. |
| | 7·3 | En. s. |
| | 11·3 | Mi. n. |
| 18 | 4·4 | Te. n. |
| | 9·9 | Mi. n. |
| | 13·0 | Di. n. |
| | 16·2 | En. s. |
| 19 | 3·1 | Te. s. |
| | 8·6 | Mi. n. |
| | 8·6 | En. n. |
| | 11·1 | Rh. s. |
| | 21·9 | Di. s. |
| 20 | 1·7 | Te. n. |
| | 17·5 | En. n. |
| | 18·5 | Mi. s. |
| 21 | 0·3 | Te. s. |
| | 6·7 | Di. n. |
| | 9·9 | En. s. |
| | 17·1 | Mi. s. |
| | 17·2 | Rh. n. |
| | 23·0 | Te. n. |
| 22 | 15·5 | Di. s. |
| | 15·7 | Mi. s. |
| | 18·8 | En. s. |
| | 21·6 | Te. s. |
| 23 | 11·2 | En. n. |
| | 14·3 | Mi. s. |
| | 14·6 | Tit. s. 70″ |
| | 20·3 | Te. n. |
| | 23·4 | Rh. s. |
| 24 | 0·3 | Di. n. |
| | 12·9 | Mi. s. |
| | 18·9 | Te. s. |
| | 20·1 | En. n. |
| 25 | 9·2 | Di. s. |
| | 11·5 | Mi. s. |
| | 12·5 | En. s. |
| | 17·6 | Te. n. |
| 26 | 5·6 | Rh. n. |
| | 10·2 | Mi. s. |
| | 16·2 | Te. s. |
| | 18·0 | Di. n. |
| | 21·4 | En. s. |
| 27 | 13·8 | En. n. |
| | 14·9 | Te. n. |
| 28 | 2·8 | Di. s. |
| | 11·7 | Rh. s. |
| | 13·5 | Te. s. |
| 29 | 11·6 | Di. n. |
| | 12·1 | Te. n. |
| | 15·2 | En. s. |
| | 17·3 | Mi. n. |
| 30 | 7·6 | En. n. |
| | 10·8 | Te. s. |
| | 15·9 | Mi. n. |
| | 17·9 | Rh. n. |
| | 20·4 | Di. s. |
| 31 | 9·4 | Te. n. |
| | 9·6 | Tit. n. 67″ |
| Jan. 31 | 14·5 | Mi. n. |
| | 16·5 | En. n. |
| | 19·0 | Iap. s. 71″ |
| Feb. 1 | 5·3 | Di. n. |
| | 8·1 | Te. s. |
| | 8·9 | En. s. |
| | 13·1 | Mi. n. |
| 2 | 0·0 | Rh. s. |
| | 6·7 | Te. n. |
| | 11·8 | Mi. n. |
| | 14·1 | Di. s. |
| | 17·8 | En. s. |
| 3 | 5·4 | Te. s. |
| | 10·2 | En. n. |
| | 10·4 | Mi. n. |
| | 22·9 | Di. n. |
| 4 | 4·0 | Te. n. |
| | 6·2 | Rh. n. |
| | 9·0 | Mi. n. |
| | 19·1 | En. n. |
| 5 | 2·7 | Te. s. |
| | 7·6 | Mi. n. |
| | 7·7 | Di. s. |
| | 11·5 | En. s. |
| 6 | 1·3 | Te. n. |
| | 4·0 | En. n. |
| | 6·2 | Mi. n. |
| | 12·3 | Rh. s. |
| | 16·6 | Di. n. |
| | 23·9 | Te. s. |
| 7 | 12·8 | En. n. |
| | 16·1 | Mi. s. |
| | 22·6 | Te. n. |
| 8 | 1·4 | Di. s. |
| | 5·3 | En. s. |
| | 12·0 | Tit. s. 72″ |
| | 14·8 | Mi. s. |
| | 18·5 | Rh. n. |
| | 21·2 | Te. s. |
| 9 | 10·2 | Di. n. |
| | 13·4 | Mi. s. |
| | 14·2 | En. s. |
| | 19·9 | Te. n. |
| 10 | 6·6 | En. n. |
| | 12·0 | Mi. s. |
| | 18·5 | Te. s. |
| | 19·0 | Di. s. |
| 11 | 0·7 | Rh. s. |
| | 10·6 | Mi. s. |
| | 15·5 | En. n. |
| | 17·2 | Te. n. |
| 12 | 3·9 | Di. n. |
| | 7·9 | En. s. |
| | 9·2 | Mi. s. |
| | 15·8 | Te. s. |
| 13 | 6·8 | Rh. n. |
| | 7·8 | Mi. s. |
| | 12·7 | Di. s. |
| | 14·5 | Te. n. |

| 1888 | h | |
|---|---|---|
| Feb. 13 | 16·8 | En. s. |
| 14 | 6·4 | Mi. s. |
| | 9·2 | En. n. |
| | 13·1 | Te. s. |
| | 21·5 | Di. n. |
| 15 | 11·8 | Te. n. |
| | 13·0 | Rh. s. |
| | 16·4 | Mi. n. |
| | 18·1 | En. n. |
| 16 | 6·3 | Di. s. |
| | 7·1 | Tit. n. 68″ |
| | 10·4 | Te. s. |
| | 10·6 | En. s. |
| | 15·0 | Mi. n. |
| 17 | 9·0 | Te. n. |
| | 13·6 | Mi. n. |
| | 15·2 | Di. n. |
| | 19·2 | Rh. n. |
| | 19·4 | En. s. |
| 18 | 7·7 | Te. s. |
| | 11·9 | En. n. |
| | 12·2 | Mi. n. |
| 19 | 0·0 | Di. s. |
| | 4·3 | En. s. |
| | 6·3 | Te. n. |
| | 10·8 | Mi. n. |
| 20 | 1·3 | Rh. s. |
| | 5·0 | Te. s. |
| | 8·8 | Di. n. |
| | 9·4 | Mi. n. |
| | 13·2 | En. s. |
| 21 | 3·6 | Te. n. |
| | 5·6 | En. n. |
| | 8·1 | Mi. n. |
| | 17·7 | Di. s. |
| 22 | 2·3 | Te. s. |
| | 6·7 | Mi. n. |
| | 7·5 | Rh. n. |
| | 14·5 | En. n. |
| 23 | 0·9 | Te. n. |
| | 2·5 | Di. n. |
| | 7·0 | En. s. |
| | 23·6 | Te. s. |
| 24 | 9·5 | Tit. s. 72″ |
| | 11·3 | Di. s. |
| | 13·7 | Rh. s. |
| | 22·2 | Te. n. |
| 25 | 8·3 | En. n. |
| | 13·8 | Mi. s. |
| | 20·1 | Di. n. |
| | 20·9 | Te. s. |
| 26 | 12·4 | Mi. s. |
| | 17·1 | En. n. |
| | 19·5 | Te. n. |
| | 19·8 | Rh. n. |
| 27 | 5·0 | Di. s. |
| | 9·6 | En. s. |
| | 11·1 | Mi. s. |
| | 18·2 | Te. s. |
| Feb. 28 | 2·0 | En. n. |
| | 9·7 | Mi. s. |
| | 13·8 | Di. n. |
| | 16·8 | Te. n. |
| 29 | 2·0 | Rh. s. |
| | 8·3 | Mi. s. |
| | 10·9 | En. n. |
| | 15·5 | Te. s. |
| | 22·6 | Di. s. |
| Mar. 1 | 3·4 | En. s. |
| | 6·9 | Mi. s. |
| | 14·1 | Te. n. |
| 2 | 5·5 | Mi. s. |
| | 7·5 | Di. n. |
| | 8·2 | Rh. n. |
| | 12·2 | En. s. |
| | 12·8 | Te. s. |
| 3 | 4·7 | En. n. |
| | 4·9 | Tit. n. 68″ |
| | 11·4 | Te. n. |
| | 15·4 | Mi. n. |
| | 16·3 | Di. s. |
| 4 | 10·1 | Te. s. |
| | 13·6 | En. n. |
| | 14·1 | Mi. n. |
| | 14·4 | Rh. s. |
| 5 | 1·1 | Di. n. |
| | 6·0 | En. s. |
| | 8·7 | Te. n. |
| | 12·7 | Mi. n. |
| 6 | 7·4 | Te. s. |
| | 10·0 | Di. s. |
| | 11·3 | Mi. n. |
| | 14·9 | En. s. |
| | 20·6 | Rh. n. |
| 7 | 6·0 | Te. n. |
| | 7·3 | En. n. |
| | 9·9 | Mi. n. |
| | 18·8 | Di. n. |
| 8 | 4·7 | Te. s. |
| | 8·5 | Mi. n. |
| | 16·2 | En. n. |
| 9 | 2·7 | Rh. s. |
| | 3·3 | Te. n. |
| | 3·6 | Di. s. |
| | 7·2 | Mi. n. |
| | 8·6 | En. s. |
| 10 | 2·0 | Te. s. |
| | 12·5 | Di. n. |
| | 17·1 | Mi. s. |
| | 17·5 | En. s. |
| 11 | 0·6 | Te. n. |
| | 7·4 | Tit. s. 72″ |
| | 8·9 | Rh. n. |
| | 10·0 | En. n. |
| | 15·7 | Mi. s. |
| | 21·3 | Di. s. |
| | 23·3 | Te. s. |
| 12 | 1·0 | Iap. n. 74″ |
| Mar. 12 | 14·3 | Mi. s. |
| | 18·9 | En. n. |
| | 21·9 | Te. n. |
| 13 | 6·2 | Di. n. |
| | 11·3 | En. s. |
| | 12·9 | Mi. s. |
| | 15·1 | Rh. s. |
| | 20·6 | Te. s. |
| 14 | 3·7 | En. n. |
| | 11·6 | Mi. s. |
| | 15·0 | Di. s. |
| | 19·2 | Te. n. |
| 15 | 10·2 | Mi. s. |
| | 12·6 | En. n. |
| | 17·9 | Te. s. |
| | 21·3 | Rh. n. |
| | 23·8 | Di. n. |
| 16 | 5·1 | En. s. |
| | 8·8 | Mi. s. |
| | 16·5 | Te. n. |
| 17 | 7·4 | Mi. s. |
| | 8·7 | Di. s. |
| | 13·9 | En. s. |
| | 15·2 | Te. s. |
| 18 | 3·5 | Rh. s. |
| | 6·0 | Mi. s. |
| | 6·4 | En. n. |
| | 13·8 | Te. n. |
| | 17·5 | Di. n. |
| 19 | 2·9 | Tit. n. 68″ |
| | 12·5 | Te. s. |
| | 15·3 | En. n. |
| | 16·0 | Mi. n. |
| 20 | 2·4 | Di. s. |
| | 7·7 | En. s. |
| | 9·7 | Rh. n. |
| | 11·1 | Te. n. |
| 21 | 9·8 | Te. s. |
| | 11·2 | Di. n. |
| 22 | 8·4 | Te. n. |
| | 15·9 | Rh. s. |
| | 20·0 | Di. s. |
| 23 | 7·1 | Te. s. |
| 24 | 4·9 | Di. n. |
| | 5·8 | Te. n. |
| | 9·1 | Mi. n. |
| | 10·4 | En. s. |
| | 22·1 | Rh. n. |
| 25 | 2·8 | En. n. |
| | 4·4 | Te. s. |
| | 7·7 | Mi. n. |
| | 13·7 | Di. s. |
| 26 | 3·1 | Te. n. |
| | 6·3 | Mi. n. |
| | 11·7 | En. n. |
| | 22·6 | Di. n. |
| 27 | 1·7 | Te. s. |
| | 4·1 | En. s. |
| | 4·3 | Rh. s. |

| 1888 | h |
|---|---|
| Mar. 27 | 4·9 Mi. n. |
| | 5·7 Tit. s. 70″ |
| 28 | 0·3 Te. n. |
| | 7·4 Di. s. |
| | 13·0 En. s. |
| | 14·8 Mi. s. |
| | 23·0 Te. s. |
| 29 | 5·5 En. n. |
| | 10·5 Rh. n. |
| | 13·5 Mi. s. |
| | 16·3 Di. n. |
| | 21·7 Te. n. |
| 30 | 12·1 Mi. s. |
| | 14·4 En. n. |
| | 20·3 Te. s. |
| 31 | 1·1 Di. s. |
| | 6·8 En. s. |
| | 10·7 Mi. s. |
| | 16·8 Rh. s. |
| | 19·0 Te. n. |
| Apr. 1 | 9·3 Mi. s. |
| | 9·9 Di. n. |
| | 15·7 En. s. |
| | 17·6 Te. s. |
| 2 | 7·9 Mi. s. |
| | 8·1 En. n. |
| | 16·3 Te. n. |
| | 18·8 Di. s. |
| | 23·0 Rh. n. |
| 3 | 6·6 Mi. s. |
| | 15·0 Te. s. |
| | 17·0 En. n. |
| 4 | 1·6 Tit. n. 66″ |
| | 3·6 Di. n. |
| | 9·5 En. s. |
| | 13·6 Te. n. |
| 5 | 5·2 Rh. s. |
| | 12·3 Te. s. |
| | 12·5 Di. s. |
| 6 | 10·8 En. n. |
| | 10·9 Te. n. |
| | 13·7 Mi. n. |
| | 21·3 Di. n. |
| 7 | 3·3 En. s. |
| | 9·6 Te. s. |
| | 11·4 Rh. n. |
| | 12·4 Mi. n. |
| Apr. 8 | 6·2 Di. s. |
| | 8·2 Te. n. |
| | 11·0 Mi. n. |
| | 12·1 En. s. |
| 9 | 4·6 En. n. |
| | 6·9 Te. s. |
| | 9·6 Mi. n. |
| | 15·0 Di. n. |
| | 17·7 Rh. s. |
| 10 | 5·6 Te. n. |
| | 8·2 Mi. n. |
| | 13·5 En. n. |
| | 23·9 Di. s. |
| 11 | 4·2 Te. s. |
| | 5·9 En. s. |
| | 6·8 Mi. n. |
| | 23·9 Rh. n. |
| 12 | 2·9 Te. n. 68″ |
| | 4·6 Tit. s. |
| | 8·7 Di. n. |
| | 14·8 En. s. |
| 13 | 1·5 Te. s. |
| | 7·3 En. n. |
| | 17·6 Di. s. |
| 14 | 0·2 Te. n. |
| | 6·1 Rh. s. |
| | 14·0 Mi. s. |
| | 16·2 En. n. |
| | 22·9 Te. s. |
| 15 | 2·4 Di. n. |
| | 8·6 En. s. |
| | 12·6 Mi. s. |
| | 21·5 Te. n. |
| 16 | 11·3 Mi. s. |
| | 11·3 Di. s. |
| | 12·3 Rh. n. |
| | 17·5 En. s. |
| | 20·2 Te. s. |
| 17 | 9·9 Mi. s. |
| | 9·9 En. n. |
| | 18·8 Te. n. |
| | 20·2 Di. n. |
| 18 | 14·2 Iap. s. 72″ |
| | 17·5 Te. s. |
| | 18·6 Rh. s. |
| 19 | 5·0 Di. s. |
| | 16·2 Te. n. |
| Apr. 20 | 0·7 Tit. n. 64″ |
| | 13·9 Di. n. |
| | 14·8 Te. s. |
| 21 | 0·8 Rh. n. |
| | 13·5 Te. n. |
| | 22·7 Di. s. |
| 22 | 12·1 Te. s. |
| 23 | 7·1 Rh. s. |
| | 7·6 Di. n. |
| | 10·8 Te. n. |
| 24 | 9·5 Te. s. |
| | 16·4 Di. s. |
| 25 | 8·1 Te. n. |
| | 13·3 Rh. n. |
| 26 | 1·3 Di. n. |
| | 6·8 Te. s. |
| 27 | 5·4 Te. n. |
| | 10·2 Di. s. |
| | 19·6 Rh. s. |
| 28 | 4·0 Tit. s. 66″ |
| | 4·1 Te. s. |
| | 19·0 Di. n. |
| 29 | 2·8 Te. n. |
| 30 | 1·4 Te. s. |
| | 1·8 Rh. n. |
| | 3·9 Di. s. |
| May 1 | 0·1 Te. n. |
| | 12·7 Di. n. |
| | 22·8 Te. s. |
| 2 | 8·1 Rh. s. |
| | 21·4 Te. n. |
| | 21·6 Di. s. |
| 3 | 20·1 Te. s. |
| 4 | 6·5 Di. n. |
| | 14·3 Rh. n. |
| | 18·7 Te. n. |
| 5 | 15·3 Di. s. |
| | 17·4 Te. s. |
| 6 | 16·1 Te. n. |
| | 20·6 Rh. s. |
| 7 | 0·2 Di. n. |
| | 0·2 Tit. n. 62″ |
| | 14·7 Te. s. |
| 8 | 9·0 Di. s. |
| | 13·4 Te. n. |
| 9 | 2·8 Rh. n. |

By means of this list of conjunctions of the five inner satellites, approximate values of their co-ordinates $x$ and $y$, expressed in semi-diameters of the planet's equator, may be easily found for any other time $t$ in the following little table, the argument of which is the interval $\tau$ between the time $t$ and the time of the next preceding or following conjunction. The satellites are on the same side, north or south, of the major axis of the ring as at the time of the next conjunction, and as they move in the direction of *de*creasing position-angles, they are in the interval between

a N. and a S. conjunction on the preceding side, and between a S. and a N. conjunction on the following side of the direction of the minor axis of the ring. They are at their greatest elongations, Mi. 5·7, En. 8·2, Te. 11·3, Di. 16·4, Rh. 27·1 hours before or after the times of conjunction.

| $\tau$ | *Mimas.* | | *Enceladus.* | | *Tethys.* | | *Dione.* | | *Rhea.* | |
|---|---|---|---|---|---|---|---|---|---|---|
| h | $x_1$ | $y_1$ | $x_2$ | $y_2$ | $x_3$ | $y_3$ | $x_4$ | $y_4$ | $x_5$ | $y_5$ |
| 0 | 0·0 | 1·1 | 0·0 | 1·4 | 0·0 | 1·7 | 0·0 | 2·2 | 0·0 | 3·0 |
| 1 | 0·9 | 1·1 | 0·8 | 1·4 | 0·7 | 1·7 | 0·6 | 2·2 | 0·5 | 3·0 |
| 2 | 1·7 | 0·9 | 1·5 | 1·3 | 1·4 | 1·7 | 1·2 | 2·1 | 1·0 | 3·0 |
| 3 | 2·3 | 0·7 | 2·2 | 1·2 | 2·0 | 1·6 | 1·8 | 2·1 | 1·5 | 3·0 |
| 4 | 2·8 | 0·5 | 2·8 | 1·0 | 2·6 | 1·5 | 2·4 | 2·0 | 2·0 | 3·0 |
| 5 | 3·1 | 0·2 | 3·3 | 0·8 | 3·2 | 1·3 | 2·9 | 1·9 | 2·5 | 2·9 |
| 6 | 3·1 | 0·1 | 3·7 | 0·6 | 3·7 | 1·1 | 3·5 | 1·8 | 3·0 | 2·9 |
| 7 | 2·9 | 0·4 | 3·9 | 0·3 | 4·1 | 0·9 | 4·0 | 1·7 | 3·5 | 2·8 |
| 8 | 2·5 | 0·6 | 4·0 | 0·1 | 4·5 | 0·8 | 4·4 | 1·6 | 4·0 | 2·7 |
| 9 | 1·8 | 0·8 | 4·0 | 0·2 | 4·7 | 0·6 | 4·8 | 1·5 | 4·5 | 2·6 |
| 10 | 1·1 | 1·0 | 3·8 | 0·5 | 4·9 | 0·3 | 5·2 | 1·3 | 4·9 | 2·5 |
| 11 | | | | | 5·0 | 0·1 | 5·6 | 1·1 | 5·3 | 2·4 |
| 12 | | | | | | | 5·8 | 0·9 | 5·7 | 2·3 |
| 14 | | | | | | | 6·2 | 0·5 | 6·5 | 2·1 |
| 16 | | | | | | | 6·4 | 0·1 | 7·1 | 1·8 |
| 20 | | | | | | | | | 8·2 | 1·2 |
| 27·1 | | | | | | | | | 8·9 | 0·0 |

Observers who are desirous to follow the motions of the satellites will find it of service to lay down the data of the table graphically on a sufficiently large scale, so that, by marking the corresponding times for the night of observing, they may get information about the places of the satellites at a glance.

Careful observations of the position-angles of the satellites at the times of their passing the direction of the minor axis of the ring afford the best means for determining the longitudes of the satellites in their orbits and are least liable to systematic errors, so that their evidence must be of very great weight in settling any questions concerning the orbital longitudes.

As the present apparition of *Saturn* is the last one, for some years to come, which will allow observations of the conjunctions of *Mimas* with the centre of the ball, it is to be hoped that the opportunities for observing such conjunctions with the powerful telescopes now available will not be neglected.

*Approximate Differences of Right Ascension and Declination between the three outer Satellites and the Centre of Saturn.*

| Greenwich Noon. 1887. | | Titan. $\alpha_6-A.$ | Titan. $\delta_6-D.$ | Hyperion. $\alpha_7-A.$ | Hyperion. $\delta_7-D.$ | Iapetus. $\alpha_8-A.$ | Iapetus. $\delta_8-D.$ |
|---|---|---|---|---|---|---|---|
| | | s | ″ | s | ″ | s | ″ |
| Oct. | 15 | −12·34 | − 2·1 | − 1·68 | +60·0 | −23·92 | +16·2 |
| | 16 | −12·97 | −25·4 | − 6·56 | +47·2 | 26·13 | 11·5 |
| | 17 | −11·71 | −45·0 | −10·73 | +29·1 | −28·19 | − 6·7 |
| | 18 | − 8·79 | −58·3 | −13·82 | + 7·9 | 30·07 | + 1·9 |
| | 19 | − 4·63 | −63·4 | −15·65 | −14·1 | −31·75 | − 2·9 |
| | 20 | + 0·20 | −59·6 | −16·18 | −35·0 | 33·23 | 7·7 |
| | 21 | + 5·02 | −47·3 | −15·49 | −53·3 | −34·49 | −12·4 |
| | 22 | + 9·12 | −28·1 | −13·72 | −67·9 | 35·52 | 17·0 |
| | 23 | −11·86 | − 4·6 | −11·05 | −78·2 | −36·33 | −21·5 |
| | 24 | +12·76 | +19·7 | − 7·67 | −83·5 | 36·90 | 25·9 |
| | 25 | +11·61 | +40·8 | − 3·80 | −83·6 | −37·22 | −30·1 |
| | 26 | + 8·55 | +55·2 | + 0·32 | −78·6 | 37·30 | 34·1 |
| | 27 | + 4·05 | +60·5 | + 4·43 | −68·5 | −37·14 | −37·9 |
| | 28 | − 1·14 | +55·7 | + 8·25 | −53·9 | 36·74 | 41·4 |
| | 29 | − 6·16 | +41·8 | +11·50 | −35·4 | −36·09 | −44·7 |
| | 30 | −10·22 | +21·1 | +13·87 | −14·1 | 35·21 | 47·7 |
| | 31 | −12·72 | − 2·9 | +15·04 | + 8·5 | −34·10 | −50·5 |
| Nov. | 1 | −13·33 | −26·6 | +14·78 | +30·3 | 32·76 | 52·9 |
| | 2 | −12·00 | −46·4 | +12·95 | +48·9 | −31·21 | −54·9 |
| | 3 | − 8·96 | −59·8 | + 9·60 | +61·8 | 29·46 | 56·6 |
| | 4 | − 4·64 | −64·7 | + 5·06 | +67·2 | −27·52 | −58·0 |
| | 5 | + 0·35 | −60·6 | − 0·12 | +64·1 | 25·39 | 59·1 |
| | 6 | + 5·30 | −47·7 | − 5·32 | +53·1 | −23·10 | −59·8 |
| | 7 | + 9·49 | −27·8 | − 9·93 | +36·0 | 20·66 | 60·1 |
| | 8 | +12·26 | − 3·7 | −13·52 | +14·9 | −18·08 | −60·1 |
| | 9 | +13·12 | +21·1 | −15·85 | − 7·6 | 15·38 | 59·7 |
| | 10 | +11·87 | +42·5 | −16·83 | −29·6 | −12·57 | −58·9 |
| | 11 | + 8·65 | +57·0 | −16·52 | −49·4 | 9·67 | 57·8 |
| | 12 | + 3·97 | +62·0 | −15·03 | −65·7 | − 6·71 | −56·4 |
| | 13 | − 1·38 | +56·7 | −12·53 | −77·8 | 3·69 | 54·6 |
| | 14 | − 6·54 | +42·0 | − 9·22 | −85·0 | − 0·64 | −52·5 |
| | 15 | −10·67 | +20·6 | − 5·33 | −86·9 | + 2·42 | 50·1 |
| | 16 | −13·17 | − 4·1 | − 1·09 | −83·4 | + 5·49 | −47·4 |
| | 17 | −13·70 | −28·3 | + 3·24 | −74·7 | 8·53 | 44·4 |
| | 18 | −12·25 | −48·5 | + 7·36 | −60·7 | +11·54 | −41·2 |
| | 19 | − 9·04 | −61·9 | +10·97 | −42·7 | 14·50 | 37·7 |

| Greenwich Noon. 1887. | | $\alpha_6-A.$ | $\delta_6-D.$ | $\alpha_7-A.$ | $\delta_7-D.$ | $\alpha_8-A.$ | $\delta_8-D.$ |
|---|---|---|---|---|---|---|---|
| | | s | ″ | s | ″ | s | ″ |
| Nov. | 20 | − 4·54 | −66·6 | +13·75 | −21·2 | +17·38 | −33·9 |
| | 21 | + 0·61 | −61·8 | +15·38 | + 2·1 | 20·16 | 29·9 |
| | 22 | + 5·70 | −48·2 | +15·56 | +25·2 | +22·84 | −25·2 |
| | 23 | + 9·96 | −27·5 | +14·12 | +45·8 | 25·40 | 21·5 |
| | 24 | +12·72 | − 2·5 | +11·05 | +61·1 | +27·83 | −17·0 |
| | 25 | +13·49 | +23·0 | + 6·62 | +69·1 | 30·10 | 12·4 |
| | 26 | +12·08 | +44·8 | + 1·34 | +68·4 | +32·20 | + 7·7 |
| | 27 | + 8·66 | +59·3 | − 4·13 | +59·1 | 34·12 | − 2·9 |
| | 28 | + 3·78 | +63·9 | − 9·14 | +42·9 | +35·85 | + 1·9 |
| | 29 | − 1·76 | +57·9 | −13·19 | +21·9 | 37·38 | 6·7 |
| | 30 | − 7·02 | +42·3 | −15·98 | − 1·4 | +38·69 | +11·6 |
| Dec. | 1 | +11·19 | +19·8 | −17·38 | −24·6 | 39·78 | 16·4 |
| | 2 | −13·64 | − 5·8 | −17·40 | −46·1 | +40·64 | +21·1 |
| | 3 | −14·05 | −30·7 | −16·16 | −64·3 | 41·26 | 25·8 |
| | 4 | −12·42 | −51·2 | −13·82 | −78·2 | +41·64 | +30·3 |
| | 5 | − 9·01 | −64·6 | −10·58 | −87·2 | 41·77 | 34·7 |
| | 6 | − 4·31 | −68·6 | − 6·67 | −90·8 | +41·65 | +39·0 |
| | 7 | + 1·02 | −63·3 | − 2·32 | −88·7 | 41·28 | 43·0 |
| | 8 | + 6·26 | −49·0 | + 2·18 | −81·0 | +40·65 | +46·8 |
| | 9 | +10·50 | −26·8 | + 6·56 | −67·9 | 39·77 | 50·4 |
| | 10 | +13·20 | − 0·8 | +10·48 | −50·0 | +38·64 | +53·7 |
| | 11 | +13·82 | +25·5 | +13·62 | −28·3 | 37·27 | 56·7 |
| | 12 | +12·20 | +47·7 | +15·64 | − 4·1 | +35·67 | +59·3 |
| | 13 | + 8·54 | +62·1 | +16·21 | +20·5 | 33·84 | 61·6 |
| | 14 | + 3·44 | +66·1 | +15·11 | +43·0 | +31·78 | +63·6 |
| | 15 | − 2·25 | +59·1 | +12·31 | +60·8 | 29·51 | 65·1 |
| | 16 | − 7·60 | +42·3 | + 8·00 | +71·2 | +27·05 | +66·3 |
| | 17 | −11·75 | +18·7 | + 2·67 | +72·7 | 24·41 | 67·0 |
| | 18 | −14·09 | − 8·0 | − 3·03 | +65·1 | +21·60 | +67·3 |
| | 19 | −14·33 | −33·6 | − 8·36 | +49·7 | 18·64 | 67·2 |
| | 20 | −12·47 | −54·5 | −12·80 | +28·6 | +15·55 | +66·6 |
| | 21 | − 8·83 | −67·6 | −15·99 | + 4·6 | 12·34 | 65·6 |
| | 22 | − 3·93 | −71·3 | −17·75 | −20·0 | + 9·04 | +64·2 |
| | 23 | + 1·55 | −64·8 | −18·07 | −43·1 | 5·67 | 62·2 |
| | 24 | + 6·81 | −49·2 | −17·06 | −63·2 | + 2·26 | +59·9 |
| | 25 | +11·07 | −25·8 | −14·86 | −79·0 | − 1·17 | 57·1 |
| | 26 | +13·65 | + 1·4 | −11·69 | −89·7 | − 4·61 | +53·9 |
| | 27 | +14·06 | +28·5 | − 7·77 | −94·8 | 8·03 | 50·2 |

| Greenwich Noon. | $\alpha_6 - A.$ | $\delta_6 - D.$ | $\alpha_7 - A.$ | $\delta_7 - D.$ | $\alpha_8 - A.$ | $\delta_8 - D.$ |
|---|---|---|---|---|---|---|
| 1887. | s | " | s | " | s | " |
| Dec. 28 | +12·19 | −51·0 | − 3·35 | −94·0 | −11·39 | +46·2 |
| 29 | + 8·27 | +65·1 | + 1·29 | −87·3 | 14·69 | 41·9 |
| 30 | + 2·96 | +68·3 | + 5·85 | −74·8 | −17·89 | +37·2 |
| 31 | − 2·86 | +60·1 | +10·01 | −57·1 | 20·97 | 32·1 |
| 1888. | | | | | | |
| Jan. 1 | − 8·23 | +42·0 | +13·43 | −35·1 | −23·91 | +26·8 |
| 2 | −12·29 | +16·9 | +15·75 | −10·2 | 26·69 | 21·3 |
| 3 | −14·46 | −10·6 | +16·65 | +15·7 | −29·29 | +15·5 |
| 4 | −14·47 | −36·9 | +15·86 | +40·1 | 31·68 | 9·6 |
| 5 | −12·37 | −57·9 | +13·32 | +60·1 | −33·85 | + 3·5 |
| 6 | − 8·50 | −70·7 | + 9·17 | +72·9 | 35·79 | − 2·6 |
| 7 | − 3·41 | −73·5 | + 3·86 | +76·6 | −37·48 | − 8·8 |
| 8 | + 2·18 | −65·9 | − 1·95 | +70·6 | 38·90 | 15·0 |
| 9 | + 7·45 | −48·7 | − 7·54 | + 56·1 | −40·05 | −21·2 |
| 10 | +11·61 | −24·2 | −12·29 | + 35·1 | 40·92 | 27·2 |
| 11 | +14·00 | + 4·0 | −15·80 | + 10·4 | +41·51 | −33·1 |
| 12 | +14·17 | +31·7 | −17·86 | − 15·4 | 41·81 | 39·9 |
| 13 | +12·02 | +54·3 | −18·45 | − 40·0 | −41·81 | 44·4 |
| 14 | + 7·86 | +67·9 | −17·63 | − 61·7 | 41·52 | 49·7 |
| 15 | + 2·37 | +70·1 | −15·58 | − 79·2 | −40·95 | −54·7 |
| 16 | − 3·51 | +60·6 | −12·50 | − 91·6 | 40·09 | 59·3 |
| 17 | − 8·83 | +41·1 | − 8·62 | − 98·1 | −38·96 | −63·6 |
| 18 | −12·75 | +14·9 | − 4·20 | − 98·6 | 37·56 | 67·5 |
| 19 | −14·70 | −13·6 | + 0·50 | − 92·8 | −35·91 | −70·9 |
| 20 | −14·46 | −40·3 | + 5·16 | − 81·0 | 34·02 | 73·9 |
| 21 | −12·10 | −61·1 | + 9·46 | − 63·6 | −31·89 | −76·4 |
| 22 | − 8·01 | −73·7 | +13·07 | − 41·6 | 29·55 | 78·4 |
| 23 | − 2·79 | −75·2 | +15·63 | − 16·2 | −27·02 | −80·0 |
| 24 | + 2·84 | −66·7 | +16·80 | + 10·7 | 24·31 | 81·0 |
| 25 | + 8·05 | −47·8 | +16·31 | + 36·6 | −21·44 | −81·4 |
| 26 | +12·06 | −22·2 | +14·04 | + 58·4 | 18·43 | 81·4 |
| 27 | +14·21 | + 6·9 | +10·11 | + 73·4 | −15·30 | −80·8 |
| 28 | +14·10 | +34·9 | + 4·92 | + 79·2 | 12·08 | 79·6 |
| 29 | +11·69 | +57·3 | − 0·90 | + 75·0 | − 8·78 | −78·0 |
| 30 | + 7·32 | +70·1 | − 6·62 | + 61·6 | 5·43 | 75·8 |
| 31 | + 1·73 | +71·2 | −11·58 | + 41·0 | − 2·04 | −73·2 |
| Feb. 1 | − 4·16 | +60·4 | −15·33 | + 16·1 | + 1·37 | 70·0 |
| 2 | − 9·36 | +39·6 | −17·65 | − 10·4 | + 4·76 | −66·4 |
| 3 | −13·07 | +12·5 | −18·47 | − 36·1 | 8·12 | 62·3 |

| Greenwich Noon. 1888. | | $\alpha_6$−A. | $\delta_6$−D. | $\alpha_7$−A. | $\delta_7$−D. | $\alpha_8$−A. | $\delta_8$−D. |
|---|---|---|---|---|---|---|---|
| | | s | ″ | s | ″ | s | ″ |
| Feb. | 4 | −14·77 | −16·6 | −17·87 | − 59·2 | +11·42 | −57·8 |
| | 5 | −14·26 | −43·3 | −16·00 | − 78·0 | 14·65 | 53·0 |
| | 6 | −11·68 | −63·8 | −13·06 | − 91·7 | +17·79 | −47·8 |
| | 7 | − 7·43 | −75·2 | − 9·29 | − 99·6 | 20·82 | 42·3 |
| | 8 | − 2·13 | −75·9 | − 4·94 | −101·3 | +23·73 | −36·4 |
| | 9 | + 3·46 | −65·9 | − 0·28 | − 96·6 | 26·48 | 30·3 |
| | 10 | + 8·55 | −46·2 | + 4·39 | − 85·6 | +29·07 | −23·9 |
| | 11 | +12·35 | −19·7 | + 8·75 | − 69·0 | 31·49 | 17·3 |
| | 12 | +14·24 | + 9·8 | +12·47 | − 47·3 | +33·71 | −10·7 |
| | 13 | +13·87 | +37·8 | +15·21 | − 22·0 | 35·72 | − 3·9 |
| | 14 | +11·23 | +59·6 | +16·62 | + 5·2 | +37·52 | + 2·9 |
| | 15 | + 6·72 | +71·4 | +16·42 | + 31·9 | 39·09 | 9·8 |
| | 16 | + 0·86 | +71·3 | +14·48 | + 55·1 | +40·42 | +16·6 |
| | 17 | − 4·72 | +59·3 | +10·86 | + 71·9 | 41·51 | 23·3 |
| | 18 | − 9·75 | +37·6 | + 5·89 | + 79·8 | +42·34 | +29·9 |
| | 19 | −13·22 | + 9·9 | + 0·20 | + 77·6 | 42·91 | 36·4 |
| | 20 | −14·66 | −19·4 | − 5·52 | + 65·7 | +43·23 | +42·7 |
| | 21 | −13·92 | −45·8 | −10·59 | + 46·2 | 43·29 | 48·7 |
| | 22 | −11·16 | −65·5 | −14·54 | + 21·8 | +43·08 | +54·4 |
| | 23 | − 6·81 | −76·0 | −17·08 | − 4·8 | 42·60 | 59·8 |
| | 24 | − 1·51 | −75·6 | −18·15 | − 31·0 | +41·87 | +64·9 |
| | 25 | + 3·99 | −64·6 | −17·79 | − 54·8 | 40·89 | 69·6 |
| | 26 | + 8·90 | −44·2 | −16·16 | − 74·7 | +39·66 | +73·8 |
| | 27 | +12·47 | −17·2 | −13·44 | − 89·5 | 38·19 | 77·6 |
| | 28 | +14·11 | +12·3 | − 9·86 | − 98·6 | +36·48 | +81·0 |
| | 29 | +13·50 | +39·9 | − 5·68 | −101·5 | 34·54 | 83·8 |
| Mar. | 1 | +10·70 | +60·8 | − 1·15 | − 98·1 | +32·40 | +86·0 |
| | 2 | + 6·11 | +71·6 | + 3·44 | − 88·4 | 30·06 | 87·7 |
| | 3 | + 0·52 | +70·4 | + 7·78 | − 72·9 | +27·53 | +88·9 |
| | 4 | − 5·15 | +57·5 | +11·56 | − 52·3 | 24·82 | 89·5 |
| | 5 | −10·01 | +35·2 | +14·44 | − 27·7 | +21·98 | +89·5 |
| | 6 | −13·20 | + 7·4 | +16·09 | − 0·7 | 19·00 | 88·9 |
| | 7 | −14·41 | −21·6 | +16·23 | + 25·9 | +15·91 | +87·8 |
| | 8 | −13·48 | −47·3 | +14·68 | + 50·0 | 12·72 | 86·0 |
| | 9 | −10·60 | −66·2 | +11·46 | + 68·2 | + 9·46 | +83·7 |
| | 10 | − 6·23 | −75·6 | + 6·85 | + 78·1 | 6·14 | 80·8 |
| | 11 | − 0·99 | −74·4 | + 1·39 | + 78·1 | + 2·80 | +77·4 |
| | 12 | + 4·37 | −62·6 | − 4·22 | + 68·4 | − 0·55 | 73·4 |

| Greenwich Noon. 1888. | | $\alpha_6-A$. | $\delta_6-D$. | $\alpha_7-A$. | $\delta_7-D$. | $\alpha_8-A$. | $\delta_8-D$. |
|---|---|---|---|---|---|---|---|
| | | s | ″ | s | ″ | s | ″ |
| Mar. | 13 | + 9·08 | −41·8 | − 9·33 | +50·6 | − 3·88 | +68·9 |
| | 14 | +12·42 | −14·8 | −13·42 | +27·4 | 7·18 | 64·0 |
| | 15 | +13·84 | +14·3 | −16·19 | + 1·5 | −10·42 | +58·7 |
| | 16 | +13·06 | +41·1 | −17·53 | −24·5 | 13·57 | 52·9 |
| | 17 | +10·15 | +61·1 | −17·48 | −48·6 | −16·62 | +46·8 |
| | 18 | + 5·57 | +70·9 | −16·15 | −69·0 | 19·55 | 40·4 |
| | 19 | + 0·06 | +68·8 | −13·74 | −84·7 | −22·33 | +33·7 |
| | 20 | − 5·43 | +55·3 | −10·44 | −95·0 | 24·95 | 26·8 |
| | 21 | −10·03 | +32·8 | − 6·51 | −99·3 | −27·39 | +19·7 |
| | 22 | −13·04 | + 5·3 | − 2·18 | −97·4 | 29·63 | 12·5 |
| | 23 | −14·05 | −23·0 | + 2·26 | −89·4 | −31·66 | + 5·2 |
| | 24 | −12·99 | +47·9 | + 6·54 | −75·5 | 33·46 | − 2·2 |
| | 25 | −10·03 | −65·8 | +10·35 | −56·5 | −35·03 | − 9·4 |
| | 26 | − 5·73 | −74·3 | +13·37 | −33·4 | 36·35 | 16·6 |
| | 27 | − 0·59 | −72·4 | +15·28 | − 7·6 | −37·42 | −23·6 |
| | 28 | + 4·60 | −60·2 | +15·78 | +18·8 | 38·23 | 30·4 |
| | 29 | + 9·11 | −39·3 | +14·69 | +43·1 | −38·77 | −37·0 |
| | 30 | +12·25 | −12·7 | +11·96 | +62·5 | 39·05 | 43·4 |
| | 31 | +13·49 | +15·7 | + 7·80 | +74·2 | −39·07 | −49·4 |
| April | 1 | +12·59 | +41·5 | + 2·69 | +76·7 | 38·82 | 55·0 |
| | 2 | + 9·65 | +60·4 | − 2·74 | +69·6 | −38·32 | −60·3 |
| | 3 | + 5·11 | +69·2 | − 7·83 | +54·2 | 37·57 | 65·1 |
| | 4 | − 0·25 | +66·5 | −12·05 | +32·9 | −36·57 | −69·5 |
| | 5 | − 5·56 | +52·8 | −15·06 | + 8·3 | 35·33 | 73·4 |
| | 6 | − 9·96 | +30·6 | −16·68 | −16·9 | −33·87 | −76·8 |
| | 7 | −12·78 | + 3·6 | −17·01 | −40·7 | 32·19 | 79·7 |
| | 8 | −13·64 | −23·8 | −16·06 | −61·4 | −30·32 | −82·0 |
| | 9 | −12·52 | −47·6 | −14·02 | −77·9 | 28·26 | 83·8 |
| | 10 | − 9·60 | −64·5 | −11·07 | −89·2 | −26·03 | −85·1 |
| | 11 | − 5·33 | −72·3 | − 7·45 | −94·9 | 23·65 | 85·8 |
| | 12 | − 0·34 | −69·8 | − 3·38 | −94·8 | −21·12 | −86·0 |
| | 13 | + 4·68 | −57·5 | + 0·89 | −88·7 | 18·48 | 85·7 |
| | 14 | + 9·01 | −37·0 | + 5·07 | −77·0 | −15·74 | −84·5 |
| | 15 | +11·98 | −11·1 | + 8·90 | −60·0 | 12·91 | 83·4 |
| | 16 | +13·10 | +16·4 | +12·06 | −38·8 | −10·01 | −81· |
| | 17 | +12·14 | +41·1 | +14·24 | −14·6 | 7·06 | 79·1 |
| | 18 | + 9·21 | +59·0 | +15·14 | +10·8 | − 4·09 | −76·2 |
| | 19 | + 4·77 | +67·1 | +14·55 | +34·9 | + 1·11 | 73·0 |

| Greenwich Noon. 1888. | | $\alpha_6 - A.$ | $\delta_6 - D.$ | $\alpha_7 - A.$ | $\delta_7 - D.$ | $\alpha_8 - A.$ | $\delta_8 - D.$ |
|---|---|---|---|---|---|---|---|
| | | s | ″ | s | ″ | s | ″ |
| April | 20 | − 0·44 | +63·9 | +12·38 | +55·1 | + 1·87 | −69·3 |
| | 21 | − 5·57 | +50·5 | + 8·75 | +68·7 | 4·83 | 65·2 |
| | 22 | − 9·79 | +28·6 | + 4·06 | +73·6 | + 7·74 | −60·7 |
| | 23 | −12·46 | + 2·5 | − 1·12 | +69·4 | 10·60 | 55·9 |
| | 24 | −13·25 | −23·8 | − 6·16 | +56·8 | 13·39 | −50·9 |
| | 25 | −12·09 | −46·6 | −10·49 | +38·0 | 16·09 | 45·6 |
| | 26 | − 9·22 | −62·6 | −13·75 | +15·3 | +18·68 | −40·1 |
| | 27 | − 5·06 | −69·7 | −15·75 | − 8·7 | 21·16 | 34·4 |
| | 28 | − 0·21 | −67·1 | −16·45 | −31·9 | +23·51 | −28·5 |
| | 29 | + 4·65 | −54·9 | −15·92 | −52·6 | 25·71 | 22·6 |
| | 30 | + 8·82 | −34·9 | −14·30 | −69·5 | +27·76 | −16·6 |
| May | 1 | +11·67 | − 9·9 | −11·75 | −81·9 | 29·65 | 10·5 |
| | 2 | +12·71 | +16·5 | − 8·48 | −89·1 | +31·37 | − 4·4 |
| | 3 | +11·74 | +40·2 | | | 32·90 | + 1·7 |
| | 4 | + 8·87 | +57·1 | | | +34·24 | + 7·7 |
| | 5 | + 4·54 | +64·6 | | | 35·38 | 13·6 |
| | 6 | − 0·52 | +61·3 | | | +36·32 | +19·3 |
| | 7 | − 5·49 | +47·9 | | | 37·05 | 24·9 |
| | 8 | − 9·56 | +26·9 | | | +37·57 | +30·4 |
| | 9 | −12·13 | + 1·8 | | | 37·88 | 35·6 |
| | 10 | −12·87 | −23·4 | | | +37·97 | +40·5 |
| | 11 | −11·73 | −45·1 | | | 37·85 | 45·1 |
| | 12 | − 8·93 | −60·3 | | | +37·51 | +49·5 |

## *Ephemeris of the Satellite of Neptune*, 1887–88. By A. Marth.

| Greenwich Noon. 1887. | P′ | a | b | u−U | Diff. | U | B |
|---|---|---|---|---|---|---|---|
| | ° | ″ | ″ | ° | ° | ° | ° |
| Oct. 25 | 322·70 | 16·92 | 8·29 | 169·36 | 612·32 | 131·73 | −29·34 |
| Nov. 4 | 322·51 | 16·95 | 8·28 | 61·68 | ·30 | 132·00 | 29·23 |
| 14 | 322·30 | ·97 | ·26 | 313·98 | ·28 | 132·29 | 29·12 |
| 24 | 322·07 | ·97 | ·23 | 206·26 | ·27 | 132·58 | 29·00 |
| Dec. 4 | 321·84 | 16·96 | 8·19 | 98·53 | ·28 | 132·87 | 28·88 |
| 14 | 321·62 | ·92 | ·14 | 350·81 | ·29 | 133·14 | 28·76 |
| 24 | 321·43 | ·87 | ·09 | 243·10 | ·33 | 133·38 | 28·65 |
| 1888. | | | | | | | |
| Jan. 3 | 321·27 | 16·81 | 8·04 | 135·43 | 612·36 | 133·58 | −28·56 |
| 13 | 321·14 | ·73 | 7·98 | 27·79 | ·41 | ·74 | ·48 |
| 23 | 321·06 | ·65 | ·92 | 280·20 | ·46 | ·85 | ·43 |
| Feb. 2 | 321·02 | 16·56 | 7·87 | 172·66 | ·52 | 133·90 | 28·39 |
| 12 | 321·02 | ·46 | ·83 | 65·18 | ·57 | ·89 | ·38 |
| 22 | 321·07 | ·37 | ·79 | 317·75 | ·64 | ·82 | ·40 |
| Mar. 3 | 321·17 | 16·28 | 7·75 | 210·39 | ·69 | 133·69 | 28·45 |
| 13 | 321·31 | ·19 | ·73 | 103·08 | ·74 | ·51 | ·51 |
| 23 | 321·49 | ·11 | ·71 | 355·82 | 612·80 | ·28 | ·60 |
| Apr. 2 | 321·70 | 16·04 | 7·70 | 248·62 | | 133·01 | −28·71 |

P′ position-angle of the minor axis of the satellite's apparent orbit, in the direction of superior conjunction.

*a*, *b*, major and minor semi-axes of the apparent orbit.

*u*−U, longitude of the satellite in its orbit, reckoned from the point which is in superior conjunction with the planet or in opposition to the earth.

U+180°, planetocentric longitude of the earth, reckoned in the satellite's orbit from the ascending node on the celestial equator.

B, planetocentric latitude of the earth above the plane of the orbit.

The values of *u*—U, P′, *a*, *b* are to be interpolated directly for the times for which the apparent positions of the satellite are required, and the position-angles *p* and distances *s* of the satellites are then found by means of the formulæ

$$s \sin (P'-p) = a \sin (u-U)$$
$$s \cos (P'-p) = b \cos (u-U).$$

The satellite moves in the direction of decreasing position-angles and will be at its greatest elongations (*nf* in pos. P′ +90°, *sf* in pos. P′−90° at dist. *a*) and at its nearest conjunc-

tions (superior *sup.* in pos. P′, inferior *in.* in pos. P + 180° at dist. *b*) with the planet at the following Greenwich hours:

| 1887. | | h | | 1887. | | h | | 1888. | | h | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. | 25 | 4.2 | in. | Dec. | 15 | 14.9 | sp. | Feb. | 3 | 14.1 | nf. |
| | 26 | 15.4 | nf. | | 17 | 2.2 | in. | | 5 | 1.4 | sup. |
| | 28 | 2.7 | sup. | | 18 | 13.4 | nf. | | 6 | 12.7 | sp. |
| | 29 | 14.0 | sp. | | 20 | 0.7 | sup. | | 7 | 23.9 | in. |
| | 31 | 1.3 | in. | | 21 | 12.0 | sp. | | 9 | 11.2 | nf. |
| Nov. | 1 | 12.5 | nf. | | 22 | 23.3 | in. | | 10 | 22.5 | sup. |
| | 2 | 23.8 | sup. | | 24 | 10.5 | nf. | | 12 | 9.7 | sp. |
| | 4 | 11.1 | sp. | | 25 | 21.8 | sup. | | 13 | 21.0 | in. |
| | 5 | 22.4 | in. | | 27 | 9.1 | sp. | | 15 | 8.3 | nf. |
| | 7 | 9.7 | nf. | | 28 | 20.4 | in. | | 16 | 19.5 | sup. |
| | 8 | 20.9 | sup. | | 30 | 7.6 | nf. | | 18 | 6.8 | sp. |
| | 10 | 8.2 | sp. | | 31 | 18.9 | sup. | | 19 | 18.0 | in. |
| | 11 | 19.5 | in. | 1888. | | | | | 21 | 5.3 | nf. |
| | 13 | 6.8 | nf. | Jan. | 2 | 6.2 | sp. | | 22 | 16.6 | sup. |
| | 14 | 18.0 | sup. | | 3 | 17.5 | in. | | 24 | 3.8 | sp. |
| | 16 | 5.3 | sp. | | 5 | 4.7 | nf. | | 25 | 15.1 | in. |
| | 17 | 16.6 | in. | | 6 | 16.0 | sup. | | 27 | 2.3 | nf. |
| | 19 | 3.9 | nf. | | 8 | 3.3 | sp. | | 28 | 13.6 | sup. |
| | 20 | 15.2 | sup. | | 9 | 14.6 | in. | Mar. | 1 | 0.8 | sp. |
| | 22 | 2.4 | sp. | | 11 | 1.8 | nf. | | 2 | 12.1 | in. |
| | 23 | 13.7 | in. | | 12 | 13.1 | sup. | | 3 | 23.3 | nf. |
| | 25 | 1.0 | nf. | | 14 | 0.4 | sp. | | 5 | 10.6 | sup. |
| | 26 | 12.3 | sup. | | 15 | 11.6 | in. | | 6 | 21.9 | sp. |
| | 27 | 23.5 | sp. | | 16 | 22.9 | nf. | | 8 | 9.1 | in. |
| | 29 | 10.8 | in. | | 18 | 10.2 | sup. | | 9 | 20.4 | nf. |
| | 30 | 22.1 | nf. | | 19 | 21.5 | sp. | | 11 | 7.6 | sup. |
| Dec. | 2 | 9.4 | sup. | | 21 | 8.7 | in. | | 12 | 18.9 | sp. |
| | 3 | 20.7 | sp. | | 22 | 20.0 | nf. | | 14 | 6.1 | in. |
| | 5 | 7.9 | in. | | 24 | 7.3 | sup. | | 15 | 17.4 | nf. |
| | 6 | 19.2 | nf. | | 25 | 18.5 | sp. | | 17 | 4.6 | sup. |
| | 8 | 6.5 | sup. | | 27 | 5.8 | in. | | 18 | 15.9 | sp. |
| | 9 | 17.8 | sp. | | 28 | 17.1 | nf. | | 20 | 3.1 | in. |
| | 11 | 5.0 | in. | | 30 | 4.3 | sup. | | 21 | 14.4 | nf. |
| | 12 | 16.3 | nf. | | 31 | 15.6 | sp. | | 23 | 1.6 | sup. |
| | 14 | 3.6 | sup. | Feb. | 2 | 2.9 | in. | | 24 | 12.9 | sp. |

The only observations of the satellite made during the last apparition, which have yet come to my knowledge, are those made by M. Perrotin with the great refractor of the Nice Observatory and published in the August number of the Paris Bulletin Astron. v. 4, p. 341. In the present ephemeris the plane of the orbit is assumed in accordance with these measures, which give approximately for 1888 N = 185°.260 J = 120°300.

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